PB187286

special studies for incinerators

FOR THE GOVERNMENT OF THE DISTRICT OF COLUMBIA

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

CONSUMER PROTECTION AND ENVIRONMENTAL HEALTH SERVICE

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

83

PB-187 286

special studies for incinerators

FOR THE GOVERNMENT OF THE DISTRICT OF COLUMBIA
DEPARTMENT OF SANITARY ENGINEERING

DAY & ZIMMERMANN, ENGINEERS AND ARCHITECTS

municipal incinerator effluent gases
control laboratory
size reduction of oversize burnable waste
size reduction of bulky metal objects by compression presses
heat recovery
can-metal recovery

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
consumer protection and environmental health service
ENVIRONMENTAL CONTROL ADMINISTRATION
solid wastes program
CINCINNATI
1968

PUBLIC HEALTH SERVICE PUBLICATION NO. 1748

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 75 cents

foreword

This report (SW–1d) was prepared by Day & Zimmermann Associates for the District of Columbia under partial support of Demonstration Grant No. D01–SW–00038–01, Solid Wastes Program, Environmental Control Administration, Consumer Protection and Environmental Health Service, Public Health Service, U.S. Department of Health, Education, and Welfare.

The report, consisting of six special studies, was prepared as part of the evaluations leading to a design for an incinerator (No. 5) for the District of Columbia. The text of this report provides a thorough technical discussion of commonly considered options in incineration. This information should be useful for other communities considering these alternatives.

preface

An estimated 800 million pounds of solid wastes of all types are produced in the United States every day. What to do with these solid wastes, how to dispose of them without needlessly endangering public health and welfare, and how to recover and reuse valuable materials now "thrown away" are among the most challenging and perplexing of current national problems. Because of lack of suitable planning, interest, and public understanding, these problems have reached such proportions that nationwide attention is demanded and action for the development of adequate solutions must be taken.

Intensified action concerning these problems was made possible by the Solid Waste Disposal Act, Title II of Public Law 89-272, which was signed by the President on October 20, 1965. This legislation directs the Secretary of the Department of Health, Education, and Welfare to initiate, encourage, and support a national program aimed at discovering and evaluating better methods of coping with the solid waste problem.

The Secretary is authorized (1) to conduct and support research on the nature and scope of the problem, on methods of more safely and efficiently collecting and disposing of solid wastes, and on techniques for recovering from solid wastes potentially valuable materials and energy; (2) to provide training and financial and technical assistance to local and state agencies so that they can survey their needs in the solid waste area and plan for the development and staffing of programs capable of meeting those needs now and in the years to come; (3) to encourage and support projects that may demonstrate new and improved methods of solid waste collection, handling, and disposal.

To carry out these responsibilities, the Solid Wastes Program was established. Among the responsibilities with which the Program is charged is that of providing grant support for demonstrations relating to the development and application of new and improved methods of solid waste collection, storage, processing and ultimate disposal; and also for studies and investigations that may lead to a demonstration of improved disposal practices, or may provide solutions for regional or national solid waste disposal problems. Associated with this is the responsibility of collecting and making available by appropriate means the results of, and other information pertaining to, such federally supported demonstrations, studies and investigations.

Accordingly this report is published to disseminate as widely as possible the information and findings of a project that has received grant support from the Solid Wastes Program. We hope that the report will provide those working in this field with useful information that will be of assistance in developing approaches to the solutions of their solid waste disposal problems.

—Richard D. Vaughan
Chief, Solid Wastes Program

PRECEDING PAGE BLANK

contents

STUDY OF MUNICIPAL INCINERATOR EFFLUENT GASES

Abstract 1
Introduction 1
Summary and Recommendations 1
Refuse Composition 3
Determination of Possible Pollution Products 3
Corrosion and Toxicity of Pollutants 8
Effects of Furnace Operation on Pollutants 9
Evaluation of Air Pollution Control Equipment 11
Estimates of Capital and Operating Costs for Air Pollution Control Equipment 16
References 17
Bibliography 19
Appendix A: Tables 10 to 36 21

CONTROL LABORATORY

Abstract 29
Introduction 29
Summary and Recommendations 29
Group I: Indicating and Recording Equipment for Incinerator Operation . . . 29
Group II: Physical Laboratory Equipment 30
Group III: Chemical Laboratory Equipment 33
Group IV: Monitoring Equipment for Test and Development Studies 36
References 37
Bibliography 38

SIZE REDUCTION OF OVERSIZE BURNABLE WASTE

Abstract 39
Introduction 39
Summary and Recommendations 39
Types of Oversize Burnable Waste 40
Disposal Methods 40
Equipment for Shredding 40
Machine Limitations 41
Effects of Shredded Material on Furnace Operations 42
Incinerators for Burning Bulky Objects 42
Equipment for Splitting Tree Stumps 43
Capital and Operating Costs 44
References 46

PRECEDING PAGE BLANK

SIZE REDUCTION OF BULKY METAL OBJECTS BY COMPRESSION PRESSES

Abstract . . . 47
Introduction . . . 47
Summary and Recommendations . . . 47
Source and Quantity of Bulky Metal Objects . . . 48
Disposal Methods . . . 48
Compression Equipment . . . 48
Proposed Equipment Installations . . . 49
Estimated Capital Investment Costs . . . 52
Estimated Operating Costs . . . 52
Table of Annual Operating Costs . . . 53
Appendix B: Representative list of manufacturers of Hydraulic Press Equipment . . . 53

HEAT RECOVERY

Abstract . . . 55
Introduction . . . 55
Summary and Recommendations . . . 55
Refuse Composition . . . 56
Effect of Incinerator Operation on Boiler Performance and Design . . . 57
Effect of Boiler Operation on Incinerator Performance and Design . . . 59
Factors Affecting Steam Generating Capacity . . . 60
Effect of Boiler Installation on Air Pollution Control Equipment . . . 62
Description of Equipment Arrangements . . . 63
Estimated Capital and Annual Operating Costs . . . 68
Value of Steam for Sale . . . 68
Sale of Steam at Proposed Plantsite . . . 70
Appendix C: Typical Municipal Refuse Ultimate Analyses . . . 71
Appendix D: History of East Coast Incinerator-Boiler Installations . . . 72
References . . . 73

CAN-METAL RECOVERY

Abstract . . . 75
Introduction . . . 75
Summary and Recommendations . . . 75
Source and Quantity of Metal Waste . . . 75
Disposal of Recovered Metal . . . 76
Available Metal Recovery Methods . . . 77
Capital Investment and Operating Costs . . . 78
Appendix E: Incinerators Practicing Metal Salvage . . . 78
Appendix F: Private Firms in the Scrap Metal Industry . . . 80
References . . . 80

study OF MUNICIPAL INCINERATOR EFFLUENT GASES

ABSTRACT

THE SCOPE of this study includes: an estimation of the chemical constituents of municipal incinerator effluent gases; the potential air pollution hazard of such chemicals; and the evaluation of various abatement devices applicable to the gas stream leaving the furnaces of a proposed 800-tons-per-day incinerator plant.

The effluent stream was found to contain inorganic and organic substances in the form of both gases and particulates. Some of these constituents in the effluent stream were found to be both toxic and corrosive when present in appreciable amounts.

Electrostatic precipitators and high energy scrubbers are two types of pollution control equipment applicable to this particular plant. Electrostatic precipitators preceded by mechanical collectors are recommended for the air pollution control equipment. The use of high energy scrubbers is considered acceptable from a performance standpoint, but esthetic objections to the vapor plume and probable thermal pollution of the water source rule out this application at the District of Columbia location.

INTRODUCTION

THE PURPOSE of this study was as follows: to estimate the types of air pollutants contributed by the gaseous stack effluents from municipal incinerators; to investigate the effects of various furnace operating variables on the emission of air pollutants; to evaluate the performance of various types of air pollution abatement devices; to develop capital and operating cost estimates for acceptable types of air pollution control equipment; to make recommendations for equipment to be installed at the proposed Incinerator No. 5 in Washington, D.C.

In making this study, it was first necessary to determine the amount and type of constituents in the effluent gases from the incinerator which could contribute to air pollution. In this determination, two approaches were used: one was analytical, and and the other was empirical, by review of actual test data.

The effects of such furnace variables—as temperature, amount of excess air, fuel bed agitation and incomplete combustion—on the generation of contaminants were reviewed.

After determination of the probable types and quantities of pollutants emitted from municipal incinerator furnaces, the effectiveness of various types of pollution control equipment was reviewed. An evaluation was made of both performance and possible operating problems, including the effect of various types of furnaces and furnace boiler combinations on equipment size and performance. Capital and operating cost estimates were developed for the types of equipment that would meet the requirements of the Federal Air Pollution Code. Conclusions and recommendations were developed based on analysis of the data obtained during this study.

SUMMARY AND RECOMMENDATIONS

The anticipated chemical pollutants in a municipal incinerator effluent gas may be grouped into two general catagories: inorganic gases and particulate matter; and, organic gases and particulate matter.

Inorganic Gases.—The inorganic gases consist primarily of oxides of sulfur, oxides of nitrogen, and ammonia. The inorganic particulates consist primarily of the oxides of such metals as aluminum, silicon, potassium, calcium, iron, titanium, zinc, sodium, and magnesium. Formation of complex oxides of aluminum and silicon is also possible.

Organic Gases.—The organic gases and particulate matter consist primarily of fatty acids, esters, aldehydes, hydrocarbons and oxides of carbon. Most are present as gases although the fatty acids may also be present as particulates.

In general, large percentages (up to 50 percent) of the particulate matter were found to be of a combustible nature. Of this combustible particluate, quantities up to 50 percent were found to be acetone-soluble.

Corrosion problems can be caused by the oxides of sulfur, nitrogen, and carbon. The oxides of such metals as sodium, potassium, iron, and zinc may also contribute to corrosion because of either the strong acidic or basic characteristics exhibited when such oxides are hydrolyzed. Products of combustion of halogenated compounds have been shown to be highly corrosive in minute quantities.

Toxic effects can result from the presence of the following pollutants if present in significant amounts: oxides of nitrogen; ammonia and its salts such as ammonium sulfate; aldehydes; esters; carbon monoxide and carbon dioxide; oxides of silicon, sodium, potassium and magnesium; polynuclear hydrocarbons; and phosgene or toluene diisocyanate.

For a given refuse composition, the quantity of particulates appears to increase with increased grate action and increased underfire airflow and to decrease with improved combustion.

The distribution of particle size appears to vary with combustion efficiency, underfire airflow and character of refuse. Furnaces operated in excess of design capacity show a larger weight of particulate matter per pound of flue gas. Size analysis of this particulate indicated low percentages of particulates smaller than 10 microns in size. Furnaces operated with low underfire air rates and at less than rated capacity show large percentages of particulates smaller than 10 microns in size.

To evaluate air pollution control equipment, a particulate loading of 3 pounds per thousand pounds of dry flue gas was selected for design purposes. The particulate matter was further stipulated to contain 30 percent by weight of particles smaller than 30 microns in size.

To obtain a dust loading in the final effluent gas which will meet the Federal Air Pollution Code requirements of less than 0.2 grain of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide, particulate control equipment having an overall efficiency of not less than 94 percent will be required. This is based upon an approximate CO_2 content in the flue gas of 6 percent at a 200 percent excess air condition.

The results of the study indicated that two types of particulate control equipment will meet the requirements of the Federal Air Pollution Code. These are the flooded plate or venturi scrubber (high energy scrubbers) and the electrostatic precipitator preceded by a mechanical collector.

Venturi and flooded plate scrubbers exhibit relatively high efficiency of particulate removal and can absorb some of the gaseous contaminants, such as ammonia (NH_3) and sulfur trioxide (SO_3). They have the disadvantages of high water consumption, high power costs, the presence of a plume of "steam" (condensed water vapor) at the stack discharge, and the problem of treating the effluent water for pH control and removal of fly ash. Construction materials must be carefully selected for corrosion protection.

Electrostatic precipitators have very high efficiency on small particles and the ability to remove in the dry state the small particulate matter in the gas stream. They have the disadvantages of large space requirements, large capital costs, and a critical operating temperature range; and, in addition, there is at present a lack of operating experience with municipal refuse fly ash from U.S. cities. Some operating difficulties with electrostatic precipitators are anticipated due to possible fouling with fatty acid particulates and cementatious fly ash. Corrosion of metallic surfaces can also occur when the precipitators are allowed to operate below the dew point of the incoming gas stream. Installation of mechanical cyclone collectors in the gas stream ahead of the electrostatic precipitators, to remove large particulate matter, is recommended.

The estimated capital and operating costs for the two basic systems for an installation at the proposed District of Columbia Incinerator No. 5 (800 tons/day) may be summarized as follows:

TABLE 1

ESTIMATED CAPITAL AND OPERATING COSTS FOR TWO INCINERATOR SYSTEMS

Type	Capital costs	Annual operating cost
Electrostatic precipitator with mechanical collector	$2, 409, 200	$512, 500
High energy scrubber	1, 838, 600	401, 000

The capital costs include all portions of the plant and equipment which vary with the type of equipment installed. They do not represent the cost of adding the equipment to a specific plant design.

We recommend that the electrostatic precipitator unit be installed at Incinerator No. 5, since the plume of steam from the high energy scrubber would be objectionable at this location. Also temperature conditions in the Anacostia River rule against its use as a water supply. The high energy scrubber installation presents a slightly more economical installation, but the additional cost of plume elimination and the river water conditions offset this advantage.

We also recommend further investigation to evaluate the anticipated polynuclear hydrocarbons, combustion products from halogenated hydrocarbons, and phosgene or toluene diisocyanate that could be present in the effluent gases from municipal incinerators since such materials exhibit highly toxic and corrosive characteristics when present in minute quantities.

REFUSE COMPOSITION

To determine the anticipated pollutants from incineration of municipal refuse, the composition of the refuse must be established. Municipal refuse is composed of many complex compounds, each varying in amount from small traces to large percentages of the total weight of refuse charged.

A typical municipal refuse contains many major classifications of waste materials. Table 2 is a typical refuse material analysis which was used in this study to determine the combustion products in the gas leaving the furnace. The percentage of certain items can vary seasonally, for example, the percent of lawn grass could range from 0 to approximately 32 percent depending upon the time of year. The figure of 1.68 percent was used as a typical average on an annual basis.

As may be seen from table 2, major classifications have been grouped according to chemical composition. Each of these groups has been further subdivided into individual chemical constituents as shown in tables 10 through 19 in the appendix.

The important chemical constituents of the refuse and the source of such items were determined and the results summarized as indicated in tables 3 and 4.

DETERMINATION OF POSSIBLE POLLUTION PRODUCTS

Two approaches were used in the determination of the possible pollution products that would be present in the gaseous effluent from municipal incinerators. One approach was to review the data and results of the actual sampling and chemical composition of the refuse. In addition to published data, some unpublished information was made available for this study. The second approach was a theoretical one in that the effluent constituents were determined by estimating the combustion products based on the chemical composition of the refuse. This second

TABLE 2

TYPICAL REFUSE ANALYSIS [1]

Refuse	Percent total refuse (by weight; dry basis)
Plants and grass:	
Evergreen trimmings	1.68
Flower garden plants	1.68
Lawn grass green	1.68
Ripe tree leaves	2.52
Total, plants and grass	7.56
Dirt and vacuum cleaner catch	2.52
Plastics	3.50
Paints, oils and removers	0.84
Glass and ceramics	8.50
Leather	0.42
Wood and balsam spruce	2.52
Rubber	0.42
Paper products:	
Newspapers	10.33
Brown papers	6.12
Corrugated boxes	23.92
Plastic coated papers	0.84
Waxed milk cartons	0.84
Tissue paper	2.18
Junk mail	3.03
Paper food cartons	1.27
Magazine paper	7.48
Total, paper products	56.01
Food wastes:	
Vegetable food wastes	2.52
Meat scraps (cooked)	2.52
Fried fats	2.52
Citrus rinds and seeds	1.68
Total, food wastes	9.24
Rags	0.84
Metals	7.53
Miscellaneous	0.10
Total	100.00

[1] Abstracted from study by Kaiser (*1*).

TABLE 3

REFUSE ANALYSIS: SUMMARY OF INORGANIC CONSTITUENTS

Item	Sources					
	Glass and ceramics	Dirt	Metals	Wood products	Food wastes	Plastics
Sulfur oxides, SO_2, SO_3	x	x	x	x	x	
Silicon dioxide, SiO_2	x	x	x			
Magnesium oxide, MgO	x	x	x			
Chromium oxide, Cr_2O_3	x	x	x			
Iron oxide, Fe_2O_3	x	x	x			
Sodium oxide, Na_2O	x	x				
Calcium oxide, CaO	x	x				
Aluminum oxide, Al_2O_3	x	x				
Potassium oxide, K_2O	x	x				
Boron oxide, B_2O_3	x					
Lead oxide, PbO	x					
Tin oxides, SnO_2, SnO	x					
Titanium oxide, TiO_2	x					
Zirconium oxide, ZrO_2	x					
Beryllium oxide, BeO	x		x			
Nickel oxide, NiO			x			
Copper oxides, CuO, Cu_2O			x			
Manganese oxide, MnO			x			
Cadmium oxide, CdO			x			
Zinc oxide, ZnO			x			
Chlorides, Cl_2 (acid and salts)						x
Fluorides, F_2 (acid and salts)						x
Ammonia, NH_3				x	x	x
Nitrogen oxides, NO_x				x	x	x

approach is essentially a qualitative one, of primary importance in determining the chemical composition of possible pollutants, but not necessarily the quantity.

In the analysis and discussion that follow, the main emphasis is placed on the following: The kinds and types of substances which are in the effluent stream; the source of such materials (type of refuse); the mechanism by which these substances could evolve during the incineration process; and, the data, published or unpublished, substantiating the existence of these substances in the gaseous effluent.

The anticipated chemicals in the incinerator flue gas can be grouped into two major categories: organic and inorganic substances, each of which can exist as gases or particulates. Data reviewed indicates that a large percentage of the partiuclate matter (up to 50 percent) was found to be combustible. Of this combustible fraction, up to 50 percent was soluble in acetone (2).

Organic Substances

The organic substances in incinerator flue gas may consist of organic acids (fatty acids), esters, aldehydes, ketones, alcohols, hydrocarbons, polynuclear hydrocarbons, halogenated hydrocarbons, and oxides of carbon (CO, CO_2). Fatty acids may exist in both the gas and particulate phase, but all the other organic substances probably exist in the gaseous state.

Organic Acids.—The organic acids normally encountered are classified as fatty acids. The important ones are formic acid, acetic acid, palmitic acid, stearic acid, oleic acid, and palmitoleic acid. These are found in the form of fats and esters of the following refuse: wood and balsam spruce; paper products; food wastes; and, plants and grass.

Table 19 in appendix A lists the above acids and additional data on their chemical structure and occurrence.

Fatty acids can be produced from the breakdown of the above types of refuse due to the high temper-

TABLE 4

REFUSE ANALYSIS: SUMMARY OF ORGANIC CONSTITUENTS

Item	Sources						
	Wood	Wood products	Food wastes	Plants and grass	Plastics	Rubber	Pressurized cans
Carbohydrates	x	x	x	x			
Lipids (fats)	x	x	x	x			
Acrylonitrile–butadiene–styrene polymers					x		
Cellulose acetate					x		
Cellulose acetate butyrate					x		
Cellulose nitrate					x		
Melamine formaldehyde					x		
Polyethylene					x		
Polyvinyl dichloride					x		
Urea formaldehyde					x		
Urethane					x		
Polymethyl methacrylate					x		
Polypropylene					x		
Polystyrene					x		
Polyvinyl acetate					x		
Polyvinyl chloride					x		
Halogenated hydrocarbons					x	x	x
Polynuclear hydrocarbons					x	x	

atures in the incinerator furnace. The most important type of reaction that probably occurs is decarboxylation. The mechanism of this type of reaction is illustrated in table 20 in appendix A.

Jacobs, Braverman, Hochheiser and Ettinger listed the organic acid content of incinerator flue gas as 25 to 133 p.p.m. based on analysis of actual samples (3). The Western Oil and Gas Association estimated the amount of organic acids as 0.6 pounds per ton of refuse burned (*4*).

It was mentioned previously that significant amounts of combustible particulates in the flue gas are acetone soluble. Since fatty acids are soluble in acetone (*5*) this tends to further substantiate the existence of such compounds in the flue gas.

Esters.—Methyl acetate, ethyl acetate, and ethyl stearate are typical esters which could be contained in the composition of the refuse. These are found in the lipid portion of wood, wood products, and food food wastes. In the thermal breakdown of such refuse, an ester would be liberated. The majority of these esters, however, will further decompose into fatty acids (*5*) as previously discussed.

Jacobs and coworkers list the ester content of incinerator flue gas as 5 to 137 p.p.m. based on chemical analysis of actual samples (3).

Aldehydes.—Acetaldehyde and formaldehyde are typical of the types of aldehydes which are most likely present in incinerator flue gas. Aldehydes can be formed from the thermal decomposition of such plastics as melamine formaldehyde and urea formaldehyde and thermal decomposition of polyhydroxy aldehydes (*6–8*). Polyhydroxy aldehydes are one of the forms of carbohydrates which are present in such refuse as wood, wood products, food waste, plants, and grass.

Jacobs and coauthors listed the amount of aldehydes as 10.8 to 82 p.p.m. based on actual sampling and analysis of incinerator flue gas samples (3). The Western Oil and Gas Association estimated the amounts of aldehydes to be 1.1 pounds per ton of refuse burned (*4*).

Ketones.—Ketones are present in the form of polyhydroxy ketones in carbohydrates (*8*). The polyhydroxy ketones will be decomposed by the heat of incineration and could liberate ketones. It is believed that these ketones would readily burn to carbon dioxide and water vapor. Review of published data did not disclose any reference to any actual or anticipated amounts of ketones in the gaseous effluent from the incinerator.

Alcohols.—Alcohols can appear as the decomposition products of carbohydrates. However, it is anticipated that the alcohol would readily burn to carbon dioxide and water in the presence of excess air (*8*). No reference to alcohols in the gaseous effluent from incinerators was discovered in the literature review.

Hydrocarbons.—Hydrocarbons are organic compounds containing only carbon and hydrogen atoms. Such hydrocarbons as ethylene, acetylene, and propylene could be generated by the thermal decomposition of many of the common plastics (*6*, *7*). Since these hydrocarbons are readily combustible, their existence in the effluent gas is highly improbable.

Polynuclear Hydrocarbons.—Polynuclear hydrocarbons can be liberated by the burning of rubber products such as tires. Pyrene and fluoranthene are the two largest polynuclear combustion products. Table 22 in the appendix to this section tabulates the amounts of polynuclear hydrocarbons found in an actual incinerator effluent gas during a period when rubber tires were burned.

Halogenated Compounds.—Halogenated hydrocarbons are used extensively in pressurized cans. Table 23 in appendix A lists some of the more common ones used. The products of combustion or decomposition from these compounds are hazardous and represent a potential toxic and corrosive problem as will be discussed in a later section of this report.

Phosgene, toluene diisocyanate, and halogenated compounds, which are highly toxic, could be evolved in the burning of urethane and polyurethane plastics.

Oxides of Carbon.—The oxides of carbon, carbon monoxide (CO) and carbon dioxide (CO_2) result from the combustion of all organic substances. The levels of CO_2 and CO in the gaseous effluent will be a function of the extent of combustion and percent excess air in the system. Carbon monoxide is the compound that is of more concern since it presents a potential health hazard. Jacobs and co-authors listed the CO content of incinerator flue gas as 35 to 400 p.p.m. based on analysis of actual samples (3).

SUMMARY OF ORGANICS

Table 5 summarizes the anticipated organic substances in the flue gas, their source, and reported amounts present. Substances such as ketones, alcohols, and hydrocarbons are not included since there has been no evidence of their presence in incinerator flue gases.

Inorganic Substances

The inorganics are classified into two major groups: Particulates and gases.

Inorganic Particulates.—Metals, glass, ceramics, and wood products are the principal sources of inorganic particulate matter. Most of the common metals and their oxides could be present in the incinerator flue gas or as slag inclusions.

Published data were reviewed on results of sampling and analysis of both incinerator slag and incinerator flue gas. These data are summarized in tables 24 through 27 in appendix A.

An analysis of these data indicates that the bulk of the inorganic particulates will be as follows: aluminum oxide, Al_2O_3; silicon dioxide, SiO_2; potassium oxide, K_2O; calcium oxide, CaO; iron oxide, Fe_2O_3; titanium oxide, TiO_2; zinc oxide, ZnO; sodium oxide, Na_2O; and magnesium oxide, MgO.

Some of these oxides may be converted to carbonates while in contact with carbon dioxide (CO_2) in the cooled flue gases (*10*). Complex oxides of aluminum and silica which are highly abrasive can also be formed.

Inorganic gases.—The major inorganic gases present in incinerator flue gases are ammonia (NH_3), nitrogen dioxide (NO_2), sulfur oxides (SO_2, SO_3), chlorine (Cl_2) or hydrogen chloride (HCl), fluorine (F_2) or hydrogen fluoride (HF) and hydrogen cyanide (HCN).

Ammonia (NH_3).—Ammonia (NH_3) can be released from the thermal decomposition of certain plastics and protein substances. Protein is a complex polyamide and the ammonia may be evolved from the functional amide group. Table 28 in appendix A illustrates the mechanism of the decomposition reaction.

Jacobs and coauthors (3) listed the amount of NH_3 in the incinerator flue gas as being 0.44 to 10 p.p.m. based on results of actual sampling and analysis. The Western Oil and Gas Association (*4*) listed the estimated amount as being 0.3 pounds per ton of refuse burned.

The small amounts of NH_3 actually present despite the potentially large source is probably due to the reactivity of NH_3. NH_3 will react with oxygen and many of the metallic oxides present in the flue gas producing such products as water vapor and nitrogen and its oxides (*8*).

Nitrogen Dioxide (NO_2).—Combustible refuse, such

TABLE 5

ANTICIPATED ORGANIC SUBSTANCES IN THE INCINERATOR EFFLUENT GAS

Kind	Source			Vary with excess air	Amounts reported
	Wood, wood products, plants and grass, food waste	Rubber	Plastics		
Organic acids:					
Formic	x				25 to 133 p.p.m.(3).
Acetic	x				
Palmitic	x				0.6 lbs./ton refuse burned (*4*).
Stearic	x				
Oleic	x				
Palmitoleic	x				
Esters:					
Methyl acetate	x				5 to 137 p.p.m. (3).
Ethyl acetate	x				
Ethyl stearate	x				
Aldehydes:					
Acetaldehyde	x		x	x	1.7 to 3.9×10^{-4} (*9*).
Formaldehyde	x		x	x	1.1 lbs./ton refuse burned (*4*).
CO	x		x	x	35 to 400 p.p.m. (3).
CO_2	x		x	x	
Polynuclear hydrocarbons		x			
Halogenated hydrocarbons[1]			x		
Phosgene			x		

[1] Also from pressurized can chemicals.

as plastics, wood, wood products, food wastes, grass and plants, contains nitrogen, in one form or another as one of the constituents. Such refuse when subjected to the heat in the incinerator furnace can liberate nitrogen which can then be oxidized. There are several oxides of nitrogen, the most common of which are nitrogen dioxide (NO_2), nitric oxide (NO), and nitrogen trioxide (N_2O_3). It is anticipated that NO_2 will be the principal oxide present in the flue gas. Nitric oxide (NO) is readily oxidized to NO_2 and nitrogen trioxide (N_2O_3) readily decomposes to NO which will oxidize as stated to NO_2 (*12*).

Jacobs and coworkers listed the amount of NO_2 in the incinerator flue gas as 0.15 to 1.5 p.p.m. based on results of actual sampling and analysis (3). The Western Oil and Gas Association listed the estimated quantity of NO_x (tested as NO_2) as 2.1 pounds per ton of refuse burned (*4*).

Sulfur Oxides (SO_2, SO_3).—Sulfur is present in proteins as the chemical bond in the helical structure and also in the functional groups of certain proteins. Sulfur can be liberated upon degradation of the protein molecules due to the heat in the incinerator furnace. The sulfur would be readily oxidized to sulfur dioxide (SO_2). Some of SO_2 thus formed could be further oxidized to sulfur trioxide (SO_3) as follows (*11*): (a) Oxidation of SO_2 by oxygen molecules in the flame; (b) catalytic oxidation of SO_2 at surfaces in the post flame region.

The above reactions are aided by the presence of nitric oxide (NO) and carbon monoxide (CO) and are not significantly affected by the presence of large amounts of carbon dioxide (CO_2) (*11*).

Jacobs and coauthors (3) listed the amount of SO_2 in the incinerator flue gas as 0.25 to 1.2 p.p.m. based on results of actual sampling and analysis. The Western Oil and Gas Association (*4*) listed the estimated quantity of SO_x (as SO_2) as 1.9 pounds per ton of refuse burned.

Sulfur oxides have also been reported in fly ash. Kaiser reported the amount of SO_x in fly ash as 3.0 percent by weight collected and 8.0 percent by weight in the emitted ash (*10*).

Chlorine (Cl_2), *Fluorine* (F_2) *and Hydrogen Cyanide*

(HCN).—The sources of these inorganic gases are as follows: Chlorine (Cl_2): vinyl plastics and propellants in pressurized cans; Fluorine (F_2): Teflon® plastics and propellants in pressurized cans; and hydrogen cyanide (HCN): methacrylate plastics. It is anticipated that these substances would be liberated when the above materials are decomposed due to the high temperatures in the incinerator furnace (*6*, *7*).

Since chlorine and fluorine have a great affinity for hydrogen they will probably be present as hydrogen chloride (HCl) and hydrogen fluoride (HF) in the flue gas.

There were no published data discovered reporting any test results or estimated amounts of these substances in incinerator flue gas.

SUMMARY OF INORGANIC GASES

Table 6 presents a summary of the anticipated gases in the incinerator flue gas, together with reference to their source (refuse) and amounts (published and unpublished data).

CORROSION AND TOXICITY OF POLLUTANTS

The corrosive and toxic properties of the anticipated chemical pollutants were reviewed by each major grouping, i.e., organic substances, inorganic particulates, and inorganic gases, and are discussed below. It should be noted that the quantities of pollutants reported in the flue gases will be significantly reduced at ground levels by dispersion from the top of chimneys or stacks at the incinerator plant.

Organic Substances

Table 29 in the appendix summarizes the organic pollutants with their toxic and corrosive characteristics. Tables 30 and 31 in appendix A contain additional data on halogenated hydrocarbons and polynuclear hydrocarbons.

From a review and analysis of the data, it appears that organic acids, aldehydes, and esters do not present any corrosion problems. Some aldehydes and esters exhibit toxic properties and could present a toxic hazard if present in considerable quantities. The organic acids do not represent any health hazard.

The oxides of carbon (CO and CO_2) do not normally present toxic and corrosive hazards. Carbon monoxide, while highly toxic, would only be present in trace amounts due to the large excess air used in incinerator operation. Carbon dioxide is dangerous in high concentration but again the high levels of excess air should result in adequate dilution. Corrosive conditions could develop if appreciable amounts of CO_2 are absorbed in water. However, the high temper-

TABLE 6

ANTICIPATED INORGANIC GASES IN THE INCINERATOR FLUE GAS

Chemical	Source		Vary with excess air	Amount
	Wood, wood products, plants and grass, food waste	Plastics		
NH_3	x	....	....	0.44–10 p.p.m. (*3*).
NO_2 (nitrogen dioxide)	x	x	x	0.3 lbs./ton refuse burned (*4*). 0.15–1.5 p.p.m. (*3*). 0.2–0.33 lbs./1,000 lbs. dry flue gas (*9*).
SO_2 (sulfur dioxide) and SO_3 (sulfur trioxide)	x	....	....	2.1 lbs./ton refuse burned (*4*). SO_3–3 and 8 percent by weight collected and emitted respectively (*10*). SO_2–0.25–1.2 p.p.m. (*3*). SO_2–1.9 lbs./ton refuse burned (*4*).
Cl_2, F_2, HCN	....	x	....	Not reported.

atures in the incinerator system decrease the solubility of CO_2 in water significantly.

The substances liberated when incinerating pressurized cans present both a toxic and corrosive hazard. Hama and Curley stated that the cause of such hazards from the halogenated hydrocarbons in the cans is not the chemicals *per se*, but the decomposition products which are highly corrosive and toxic compounds, primarily hydrogen chloride (HCl) and hydrogen fluoride (HF) (*12*).

The combustion products from the incineration of rubber products exhibit highly toxic properties as shown in table 31 (*13*).

The thermal decomposition of polyurethane type plastics could constitute a toxic hazard due to the liberation of phosgene and/or toluene diisocyanate. Phosgene as noted on table 29 is highly toxic and toluene diisocyanate exhibits similar properties as may be illustrated in published references (*14*, *15*).

Inorganic Particulates

Table 32 (appendix A) summarizes the inorganic particulates with their toxic and corrosive characteristics.

From the data presented, substances such as SiO_2, Na_2O, K_2O, and MgO could represent a potential health hazard because of their high toxic level if generated in significant quantities without adequate dispersion. Na_2O, K_2O, Fe_2O_3, and ZnO could be a cause of corrosion because of either their strong basic or acidic characteristics. There is also a possibility of the formation of complex oxides of aluminum and silica, which can be highly abrasive.

Inorganic Gases

Table 33 (appendix A) summarizes the inorganic gases with their toxic and corrosive characteristics. Corrosion experienced in combustion processes in those zones where the combustion products have been cooled has been related to the sulfur trioxide (SO_3) of the flue gas (*11*). Sulfur trioxide has been shown to be generated, in significantly large amounts, from the oxidation of SO_2 in the presence of carbon monoxide (CO) and nitric oxide (NO).

Sulfur oxides (SO_2, SO_3), ammonia (NH_3), and nitrogen dioxide (NO_2) all could be a potential toxic hazard because of their high index of toxicity. Also, ammonia could form salts such as ammonium sulfate which has had a serious physiological effect (*16*).

The presence of such compounds as HF and HCl in the flue gas could present both corrosive and toxic hazards. Although such compounds have not been reported directly as components in the flue gas, the problems relative to corrosion in incinerator boiler units may be due to these compounds. It has been shown that industrial gaseous effluents containing minute quantities of HF and HCl cause corrosion and represent a highly toxic health hazard.

EFFECTS OF FURNACE OPERATION ON POLLUTANTS

It should be recognized that the primary purpose of an incinerator plant is the reduction in volume and combustible content of the refuse to obtain maximum use of landfill space without polluting the atmosphere, ground, or water supplies with the incinerator gases or residue.

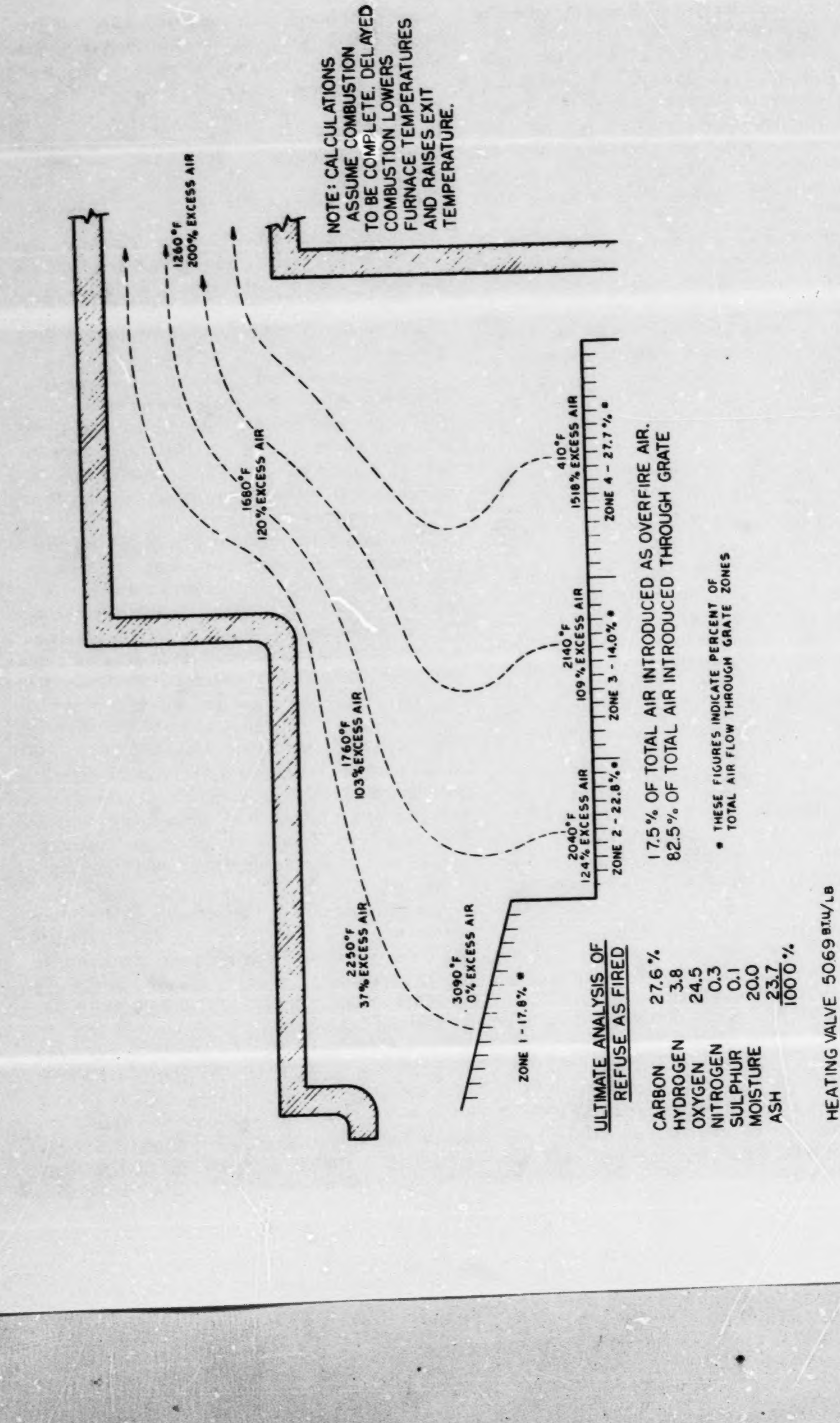
These conditions cannot be met without adequate incineration of the combustible content of the refuse. This requires a stable operating condition in the furnace to retain the combustible material and products of combustion in a furnace atmosphere that provides the necessary temperature and oxygen to ensure acceptable burnout.

There are a number of features of incinerator combustion which directly affect the composition of the effluent stream from burning refuse. The variables which have been considered are: Percent underfire air; percent overfire air; heat of incineration (furnace temperature); fuel bed agitation; incomplete combustion; oxidation; and percent excess air. The effects of these seven parameters on the effluent stream cannot always be considered individually but must be considered in conjunction with each other.

For purposes of this study, the effect of these variables has been considered for a conventional refractory wall furnace with spray cooling of the flue gas. Figure 1 illustrates design and operating conditions for such an incinerator when burning a typical refuse.

It is anticipated that the operations of this incinerator would be maintained with a total of 150 percent excess air flow through the grates and additional overfire air to bring the furnace exit gas to a condition of approximately 200 percent excess air, or 6 percent CO_2.

Maximum furnace temperature in the zone of active burning is calculated to be approximately 2,250° F. The gases would be cooled to approximately 1,260° F when they leave the furnace to enter the spray chamber by dilution with excess air and heat loss to the furnace walls. The exit gases from the furnace would


NOTE: CALCULATIONS ASSUME COMBUSTION TO BE COMPLETE. DELAYED COMBUSTION LOWERS FURNACE TEMPERATURES AND RAISES EXIT TEMPERATURE.
1260°F 200% EXCESS AIR
1680°F 120% EXCESS AIR
410°F 1518% EXCESS AIR
2140°F 109% EXCESS AIR
1760°F 103% EXCESS AIR
2040°F 124% EXCESS AIR
2250°F 37% EXCESS AIR
3090°F 0% EXCESS AIR
ZONE 1 - 17.8% •
ZONE 2 - 22.8% •
ZONE 3 - 14.0% •
ZONE 4 - 27.7% •

17.5% OF TOTAL AIR INTRODUCED AS OVERFIRE AIR.
82.5% OF TOTAL AIR INTRODUCED THROUGH GRATE

• THESE FIGURES INDICATE PERCENT OF TOTAL AIR FLOW THROUGH GRATE ZONES

ULTIMATE ANALYSIS OF REFUSE AS FIRED

CARBON	27.6%
HYDROGEN	3.8
OXYGEN	24.5
NITROGEN	0.3
SULPHUR	0.1
MOISTURE	20.0
ASH	23.7
	100.0%

HEATING VALVE 5069 B.T.U./LB

FIG. 1. *Calculated furnace conditions in a refractory furnace at 200 percent excess air.*

be cooled with water sprays to a temperature of 550° F prior to entering the air pollution control equipment.

As mentioned above, the heat of incineration (furnace temperature) plays a primary role in the generation of chemical pollutants due to thermal decomposition of refuse components. No significant correlation was found between furnace temperature and particulate emission. Higher furnace temperatures coupled with excess air availability tend to reduce the amount of organic pollutants since continuing oxidation reactions of such materials result in combustion products of carbon dioxide (CO_2) and water vapor.

The available data relating grate action to pollutant generation were very limited. It was generally indicated by extrapolation to equivalent undergrate airflows that the particulate emission increased with more violent grate action.

Available data on underfire airflow through the grates and fuel bed indicated a significant effect on the generation of particulates. Particulate weights increased quite rapidly with an increase in underfire airflow (*9*).

The distribution of particle size appeared to vary with combustion efficiency, underfire airflow, and character of refuse. Furnaces operated in excess of rated capacity showed a larger weight of particulate matter per pound of flue gas. Size analysis of this particulate indicated low percentages of particulates smaller than 10 microns in size. On the other hand, furnaces operated with low underfire air rates and at less than rated capacity showed large percentages of particulates smaller than 10 microns in size.

Increasing amounts of underfire air also tended to decrease the amount of oxides of nitrogen and aldehydes in the flue gas as illustrated in tables 34 and 35 in appendix A.

No correlation was found between overfire airflow and particulate emission. Air jetted into the fuel bed may raise particulate emission.

Higher percentages of excess air decrease the amount of carbon monoxide in the flue gas and aid the oxidation reactions, thereby decreasing the amounts of organic pollutants as mentioned above.

EVALUATION OF AIR POLLUTION CONTROL EQUIPMENT

There are three major parameters to be considered when specifying control equipment. These are as follows: Particulate loading (amount and size); volume of gas to be handled; solubility of certain constituents of the incinerator flue gas in water.

Particulate Loading

The quality of particulate matter in the furnace exit gas and the size of this particulate matter are the determining factors in selecting the efficiency requirements of the air pollution control equipment.

The review of published and unpublished test reports shows a wide range of particle size distribution between operating plants. The approximate limits of this distribution are shown by the shaded area of figure 2. The solid line in this figure represents analysis of the available data as to a representative distribution that should be obtained from normal operation of a modern continuous feed incinerator furnace. This indicates approximately 30 percent by weight of the particulate matter will be less than 10 microns in size while 75 percent by weight would be less than 250 microns in size.

The quantity of particulate matter is primarily a function of the underfire airflow through the grates (*9*). Analysis of this reference and data from other unpublished test reports indicates that approximately 3 pounds of particulate matter per thousand pounds of dry flue gas (1.61 grains per standard cubic foot) can be expected during normal operation. This is based upon an estimated average airflow through the grates equivalent to 150 percent excess air. Additional overfire air will increase the total excess air to approximately 200 percent in the flue gas entering the air pollution control equipment.

In order to obtain a dust loading which will meet the Federal Air Pollution Code Requirements of less than 0.2 grain of particulate matter per standard cubic foot of dry gas at 12 percent CO_2, particulate control equipment having an overall efficiency of not less than 94 percent will be required. This is based upon operation with an approximate CO_2 content in the flue gas of 6 percent at the 200 percent excess air conditions. The particulates at 6 percent CO_2 must be less than 0.1 grains per s.c.f. to meet the code requirements when corrected to a 12 percent CO_2 condition.

The dust loading specified above is considered to be representative for the various plant designs considered. This loading has been selected to provide for high underfire airflows in active burning areas with moderate agitation of the fuel bed providing a large mass flow of particulate matter. The percentage

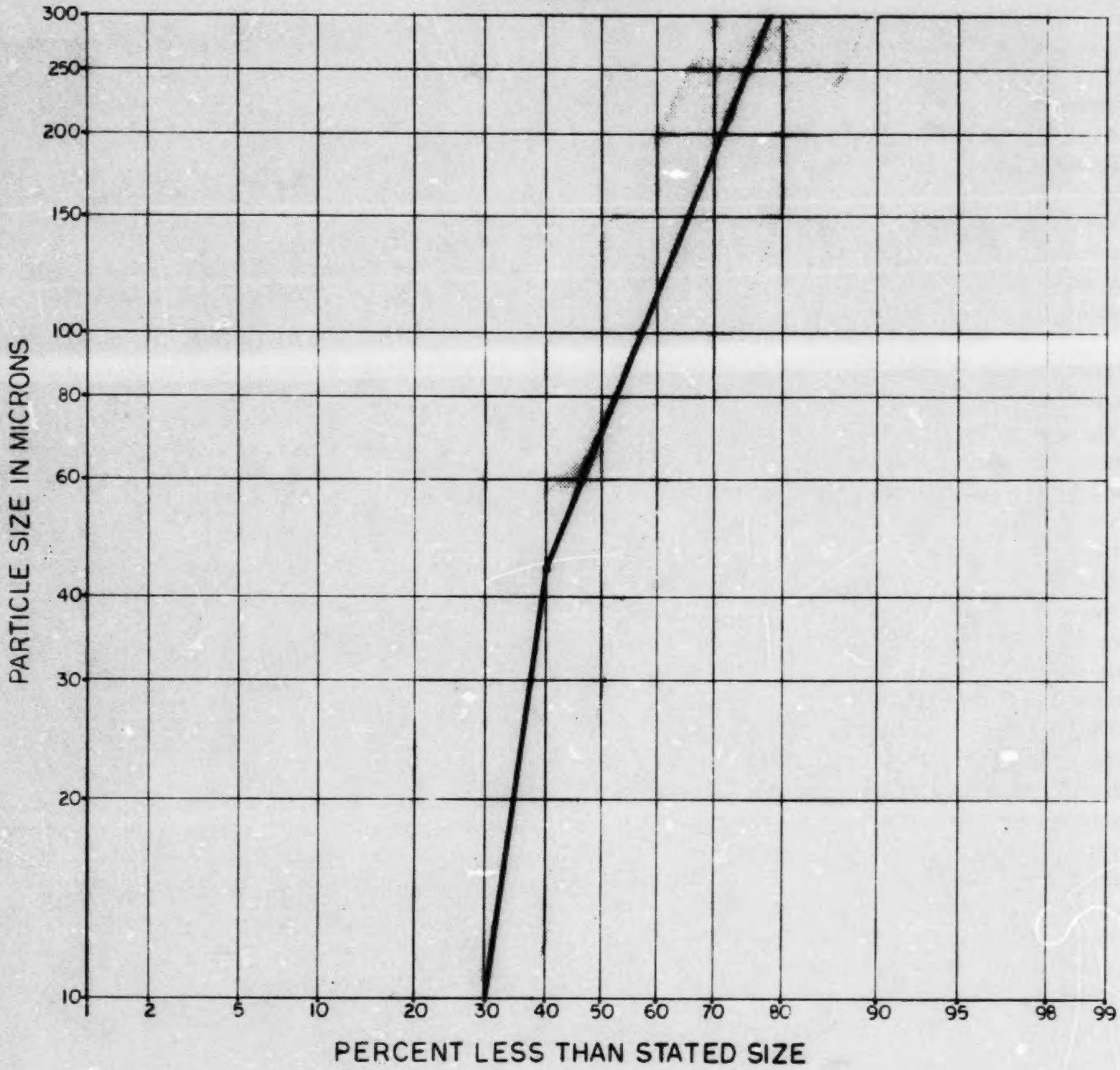


FIG. 2. *Particle size distribution in incinerator flue gas.*

of material smaller than 10 microns in size is based upon a reasonably good quality of burnout of the particulate matter in the combustion chamber.

Volume of Gas to be Handled

The use of heat recovery equipment, excess air for gas cooling or spray water for gas cooling will alter the volume of gas entering the control equipment and therefore affect the size of the equipment.

The addition of heat recovery equipment will reduce the gas volume from combustion of a given weight of refuse in two ways. First, the removal of heat from the furnace exit gases will effect a reduction in the specific volume of gas leaving the furnace. Second, equipment manufacturers recommend operation of water cooled furnaces at lower excess air levels thereby reducing total gas weight and volume.

The use of dilution air for cooling the furnace exit gases results in a maximum volume of gases entering the dust control equipment. The addition of water to the gas stream reduces gas volume and temperature by its evaporative cooling effect without adding the additional volume that dilution cooling air requires.

The net effect of the three methods of gas cooling on total gas volume is shown on the graph in figure 3. The effect of these methods of cooling the products of combustion of a 250-ton-per-day incinerator furnace operated at 150 percent excess air through the grates is indicated also in figure 3. The operating cost and the capital investment required for dust collection equipment are a function of both gas volume and

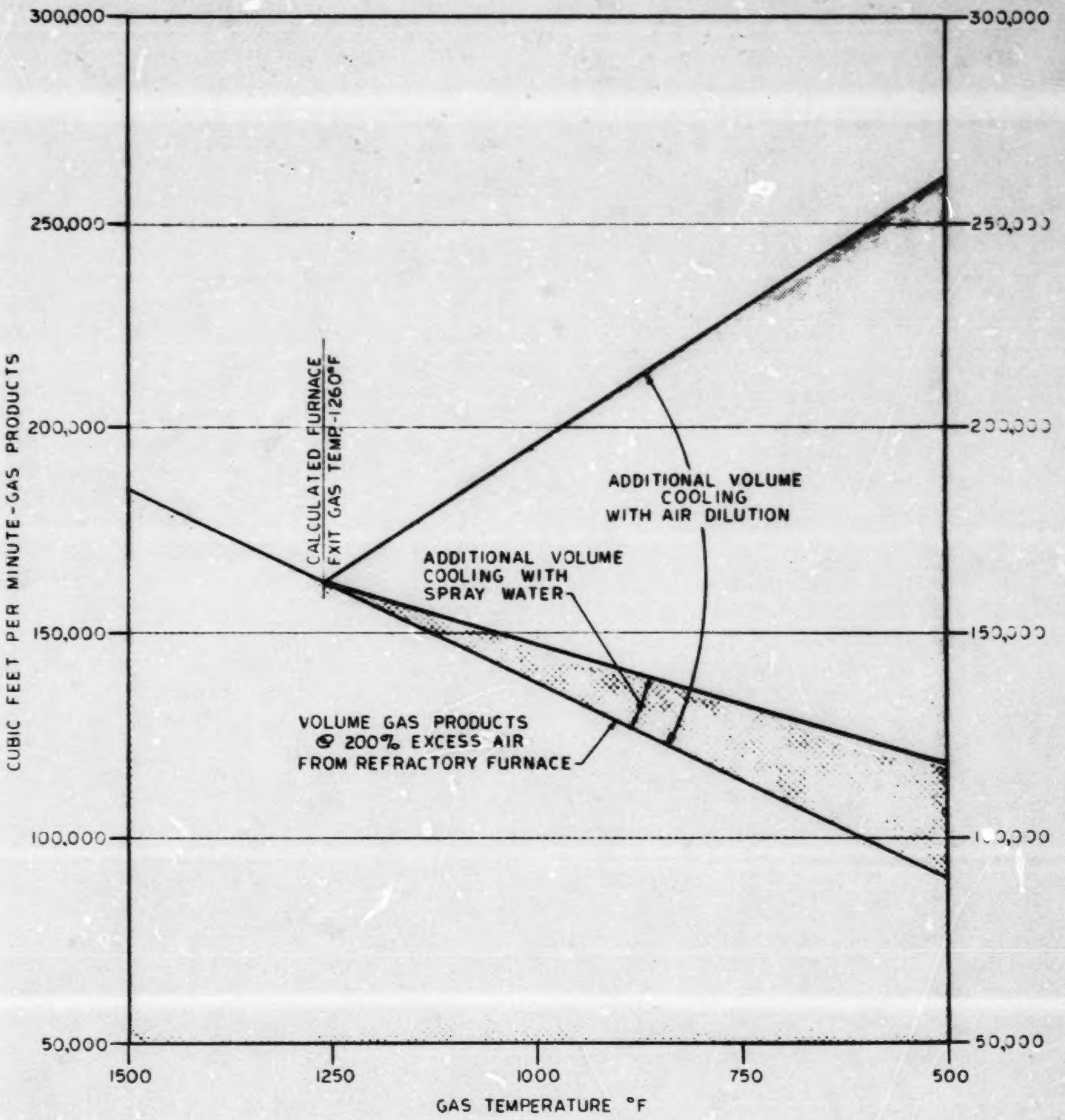


Fig. 3. *Changes in flue gas volumes as determined by gas cooling methods. Volume of products of combustion and cooling media at 150 percent undergrate excess air.*

weight. As a result, the final weight and volume determined by the method of gas cooling has an effect on annual operating expense.

Solubility of Gases in Water

Table 35 in appendix A lists the gaseous pollutants in the incinerator flue gas with their water solubility. Since a water scrubbing step is included in several of the air pollution control systems studied, the solubility in water of such pollutants must be considered.

Types of Control Equipment

For the purpose of this study, several types of air pollution control equipment were investigated to evaluate their anticipated collection efficiency, relative costs, space requirements, and operating limitations. The types of equipment considered were as follows: Settling chamber; mechanical cyclone; wet scrubber; electrostatic precipitator; and, baghouse filter.

The relative features of the above are described in the text following with a summary of pertinent data in table 7.

Settling Chamber.—In the operation of a settling chamber, the velocity of the flue gases are reduced thereby permitting the larger particles to settle out. The following settling rates indicate the gas velocities in a settling chamber must be extremely low if particles smaller than 30 microns are to be separated.

30-micron particle—settling vel. = 10′/min
10-micron particle—settling vel. = 1′/min
1-micron particle—settling vel. = 1/4′/min

To improve separation, baffles may be inserted upon which the particles will impinge. Ash retention is improved by wetting the baffles and ash removal is accomplished by flushing the ash into a wet sump.

The advantages of this type of equipment are as follows: Simplest method of fly ash control; low maintenance cost; and, capability of being operated with natural-draft chimney.

The disadvantages are as follows: Large size; high installation cost; low collection efficiencies of 40 to 60 percent; and, unsuitability for collection of smaller size particles.

Due to their low efficiency, settling chambers will not meet the air pollution code requirements unless used in conjunction with equipment of higher efficiency.

Mechanical Cyclones.—In the operation of mechanical cyclones the particles are thrown to the periphery of the cyclones by centrifugal force and are allowed to settle out.

The advantages of mechanical cyclones are the low initial cost and the low operating cost.

The disadvantages are: Low efficiency, since only larger size particles are efficiently removed; erosion of the lower tube by abrasive fly ash; and, moisture control problems.

To overcome one of the disadvantages, abrasion resistant linings may be used. Flushing of the fly ash with water has been tried in the hydrowall cyclone, a modification of the conventional cyclone which is still in the development stage.

Advantages of the hydrowall type of cyclone have been reported as follows: Reentrainment of fly ash prevented; efficiency improved; erosion reduced.

Some difficulty has been experienced with plugging of the cone sections of hydrowall installations.

Mechanical cyclones will not completely meet the air pollution code requirements. They can be of great value if used in conjunction with other equipment sich as an electrostatic precipitator which could collect the smaller size particles.

Wet Scrubbers.—There are two general classifications of wet scrubbers, the low energy type and the high energy type. In the low energy scrubbers, water is sprayed over the gas stream causing particulates to impinge on the water droplets and thereby be removed from the gas phase.

The advantagos of a low energy scrubber are as follows: Low maintenance; low cost—both initial and operating.

The disadvantages are as follows: Low efficiency. If the water droplets are larger than 200 times the diameter of the particles, the particles will not be effectively removed from the effluent stream; efficiency for removal of water soluble gases is low because of the limited amount of contact of the gas stream with the scrubbing liquid.

In a high energy scrubber the water sprays are fine and distributed more evenly, and the gas stream path is more tortuous because of the insertion of baffles, use of packing, or similar devices.

The advantages of a high energy scrubber are as follows: (1) Efficiency of ninty-five percent or greater. This is obtained by increasing the interface between the effluent gas stream and the scrubbing water. Baffles or packing increase the impingement area for removal of the particulates; (2) removal of water soluble gases. This is accomplished by increasing the amount of scrubbing liquid in contact with the gas stream. A flushing stream below the baffles or a flooded bed above the packing increases the time for removing water soluble gases; and, the (3) moderate cost of installation and operation.

The disadvantages are: (1) High maintenance cost when baffles or packing become plugged; (2) anticipated corrosion because of the change in pH of the scrubbing water after removing gases and certain particulates; (3) need for equipment to remove particulate matter from washwater and need to neutralize water before return to source; (4) difficulty with water recirculation because of particulates; (5) requirement for large flow of water; (6) a water-saturated gas is emitted from the stack, resulting in a large vapor plume which can be objectionable.

Where the vapor plume is not objectionable, the use of high energy scrubbers can meet the requirements of pollution control equipment for municipal incinerators.

Two methods can be considered for elimination of the vapor plume where such a plume is objectionable. The first method consists of reheating the stack gases to increase the temperature and thereby permitting greater dispersion of the gases in the atmosphere before condensation takes place, making the presence of moisture in the stack effluent less noticeable. The second method consists of subcooling the gases to approximately 100°F. which will reduce the total moisture content of the gas stream to about 0.10 of that present in the saturated gases at 170°F. This will reduce the total moisture content of the plume.

Water conditioning equipment must be provided to process the large quantities of water required for a high energy wet scrubber. One equipment manufacturer requires approximately 750 gallons of water per minute for a scrubber and quench unit designed to handle the products of combustion from a single incinerator furnace of the size considered in this; report. Assuming that this water is pumped from the nearby river, a river water intake of 3,000 g.p.m. capacity, suitable filtration equipment to remove solids which might plug spray nozzles and water treatment equipment to remove the fly ash from the scrubber discharge water and to neutralize the acid content of the water would be required.

It is estimated that a minimum retention time of 60 minutes would be required to obtain satisfactory clarification of the waste water stream. This would require four clarifier units, approximately 35 feet in diameter. The fine particle content of the settled slurry will make dewatering difficult, necessitating some form of slurry handling system to discharge the settled flyash to ash removal trucks. Lime and alum feed equipment should be provided to improve coagulation and neutralize the overflow before return to the river. Temperature rise of the scrubber water will be appreciable. An 18.5° F. rise is anticipated.

Total water requirements to include additional cooling of the gas to reduce the plume are estimated at 6,000 g.p.m. The temperature rise of this water would be 100° F. This would double the size of the intake structure, pumping equipment, clarifier equipment, pipelines, etc. This approach is not justified if the plume can be accepted. Likewise, gas-to-gas heat exchangers to raise the temperature of the gases are quite expensive to maintain and operate and their use is not recommended.

The Anacostia River in the District of Columbia is a tidal river with summer water temperatures approaching 100° F. Temperatures of this magnitude are unfavorable to aquatic life matter. Adding more heat from wet scrubber effluents would aggravate the existing temperature conditions. It is doubtful that permission could be obtained to return water to the river with a temperature rise in excess of 5° F. if the thermal pollution of this river is to be controlled. This 5° F. temperature rise requirement can be met only by circulation of greater quantities of water or by the addition of cooling tower facilities for heat dissipation to the atmosphere.

The adjacent electric power generating station is now in the process of installing cooling tower equipment for their latest plant expansion in order to control the water temperature to their turbine condensers.

Electrostatic Precipitators.—In the operation of electrostatic precipitators, the particles are first electrically charged and then attracted to plates which have an opposite charge. The particles lose their charge upon contact with the plates and migrate down to collection hoppers. The efficiency is dependent on the resultant vector between the inertia of the particles and electrostatic attraction to the plates.

The advantages of electrostatic precipitators are as follows: (1) Low operating cost; (2) high efficiency (90 to 99 percent); (3) highest efficiency for particles less than 10 microns in size; (4) ability to handle both dusts and mists.

The disadvantages are as follows: (1) High purchase and installation costs; (2) necessity of uniform gas distribution across inlet of collector to obtain design efficiency; (3) critical electrode voltage (too little reduces efficiency and too much causes electric arcing); (4) two limiting factors related to velocity and therefore capacity: Particles must have time to build up charge, and, gas velocity must be low enough so as not to reentrain particles; (5) the tendency of carbon to lose its charge before it is collected and high resistant inorganics are hard to charge. This can be corrected by two ways: The insertion of a cyclone before the precipitator which will remove particles greater than 10 microns in size, and, the addition of moisture to reduce the resistance of the inorganics; (6) critical temperature (optimum temperature range is 500° to 600° F. because of resistance of particles to being charged at higher or lower temperatures).

Electrostatic precipitators should meet the requirements of pollution control equipment for municipal incinerators. However, the application of an electrostatic precipitator to a U.S. municipal incinerator would be unique; therefore, serious consideration must be given to potential operating problems. These problems could consist principally of erosion, corrosion and fouling, and passing of large particulate matter.

It is probable that the problems of erosion, fouling by fatty acid particulates, and passing of large particulates can be reduced to acceptable levels if the electrostatic precipitator is preceded by a large-diameter mechanical cyclone collector constructed with an abrasion-resistant lining. This will result in a total draft loss equivalent to the wet scrubber installation. The problem of corrosion can be reduced by good temperature control equipment and adequate insulation of the equipment to reduce internal dew point condensation. There will remain a possibility of some fouling due to accumulations of cementatious fly ash. This must be considered a normal operating problem and will require internal cleaning at scheduled intervals along with other routine maintenance such as replacement of electrode wires.

The use of alkali cleaners would be effective in removing any fatty acid films. Alkaline solutions can be used satisfactorily on carbon steel and stainless alloy steels. Wash solutions are normally used between 140° to 200° F., and can be used as a spray. Wash should be followed with a rinse water spray.

Baghouse Filters.—In the operation of baghouse filters, the gases pass through the bag filter and the large particles are filtered out. After a few seconds the large particle buildup on the bag enables the smaller particles to be filtered out.

The following listing of advantages and disadvantages of using a baghouse filter is based on experience with an installation of a pilot baghouse on the municipal incinerator of the city of Pasadena, California.

The advantages are as follows: (1) High efficiency—99 percent; (2) moderate press drop, 3" to 5" water; (3) the filtering out of both small and large particulates; (4) the ability to filter out SO_3 due to nature of ash-cake on bagfilter.

The disadvantages are as follows: (1) High initial cost; (2) costly bag replacement; (3) requirement of greater control of combustion, to eliminate sticky-soot formation which clogs filters; (4) necessity to control cooling to prevent formation of moisture on filter which will shorten bag life.

Additional comments and recommendations were received from the personnel concerned with the installation at Pasadena. These may be summarized as follows: (1) The flow through the baghouse is opposite to that of conventional units. The gas enters the bag on the outside and exits through the partially collapsed bag upward through the plenum. This scheme permits the spider framework to be on the clean side of the bag and eliminates past failures due to abrasion from buildup on the spider. It also has the advantage of eliminating bag damage due to collapsing the bag over hard cakes that are periodically formed in the bag. Since the bag is normally in a semirelaxed position, the cakes that are formed can be literally "popped off" with no damage to the bag when it is inflated (cleaning cycle); (2) the flue gas should not exceed 500° F. so as to extend bag life. If this is accomplished bag life should be about 1 year; (3) cannot let unit cycle below dew point because of bag life; (4) pulsating damper speed in the cleaning fan discharge is very critical (a minimum of 250 r.p.m. to a maximum of 500 r.p.m. has some merit); (5) internal framework should be fabricated from 316 stainless steel. Carbon steel oxidizes and results in bag failure. Aluminum does not withstand prolonged elevated temperatures.

The use of a baghouse filter for air pollution control equipment for municipal incinerators should not be considered at this time due to lack of sufficient satisfactory experience.

ESTIMATES OF CAPITAL AND OPERATING COSTS FOR AIR POLLUTION CONTROL EQUIPMENT

Two concepts for removal of air pollutants from the incinerator flue gas stream were made the subject of capital investment and operating cost estimates.

In both cases gas flow is created by an induced draft fan which discharges to a 100-foot chimney.

TABLE 7

TYPES OF CONTROL EQUIPMENT

Equipment type	Comparative space (%)	Efficiency (%)	Basic limitations
Electrostatic precipitator.	100	90–99	Does not remove soluble gases. No installation working in U.S. municipal incinerators. Efficiency low on large particles.
Scrubber (flooded plate).	33	90–99	Possible mist emitting from stack. Clarification and neutralization of wash water required. High water usage.
Mechanical cyclone (60" tangential).	33	75–90	Low efficiency on small particles. Erosion from abrasive fly ash.
Baghouse filter	110	99	Multitude of variables to be controlled coupled with the complexity of the effluent stream.
Settling chamber	67	40–60	Low efficiency.

One arrangement provides for passing the 1,260° F. flue gas from the furnace through a refractory spray-cooling chamber where the temperature is reduced to 500° F. The moisture-laden gas then is passed through a multicyclone separator. The gas then enters, at a low velocity of 5 feet per second, and passes through an electrostatic precipitator unit.

The alternate concept consists of passing the hot furnace gas directly through a wet scrubber such as the flooded-plate type with a prequench unit. Water supply for this unit would be supplied from a pumping station on the Anacostia River. Water discharge from the scrubber would be delivered to a liquid clarifier. Overflow would be conducted back to the river by pipeline. Slurry removed would be pumped to residue trucks for land fill disposal.

Either of these systems are capable of removing 94 percent or more of the particulate matter over size greater than 10 microns, and close to 100 percent of particulates less than 10 microns in size.

In conclusion, we have charted annual operating costs (table 8) and estimates of some of the items adding to capital costs (table 9) for these installations. These costs are presented in some detail so that the effects of relative equipment sizes and accessory equipment can be evaluated.

It should be noted that the building costs, spray cooling chamber, steel ductwork, insulation, electrical work, and instrumentation add appreciable to the cost of installation of the electrostatic precipitator and mechanical cyclone. These higher costs are partially offset by the costs of the river water pumping station, water clarification system, refractory flues and piping for the scrubber installation.

TABLE 8

ESTIMATED ANNUAL OPERATING COSTS FOR TWO TYPES AIR POLLUTION CONTROLS[1]

Operating costs	Air pollution control equipment	
	Electrostatic and mechanical	Wet scrubber
Maintenance	$139,000	$127,700
Electric power	160,600	130,800
Purchased city water	27,900	1,000
Subtotal, operating costs	327,500	259,500
Fixed charges on capital investment 20 years at 4½ percent	185,000	141,500
Total, annual owning and operating cost	512,500	401,000

[1] Only those variables are included which are influenced by the type of equipment considered.

REFERENCES

(*1*) KAISER, E. R. Chemical analyses of refuse components. Paper 65-WA/PID-9. *In* Proceedings, American Society Mechanical Engineers, Nov. 7–11, 1965. 5 p. (Also private communications, E. R. Kaiser.)

(2) REHM, F. R. Unpublished test data.

(3) JACOBS, M. B., M. M. BRAVERMAN, S. HOCHHEISER, and I. ETTINGER. Sampling and analysis of incinerator flue gases. Paper 2464.

In Proceedings, Air Pollution Control Association, 51st Annual Meeting, Philadelphia, May 25–29, 1958.

(*4*) **Western Oil and Gas Association.** The smog problem in Los Angeles County. Los Angeles, Western Oil and Gas Association, 1954.

TABLE 9

COMPARATIVE CAPITAL COST ESTIMATES, SELECTED ITEMS FOR AIR POLLUTION CONTROL STUDY, FOUR-UNIT INCINERATOR PLANT

	Type of air pollution control equipment	
	Electro-static and mechanical	Wet scrubber
General building contract:		
Incinerator building and foundations	$606, 700	$447, 000
River pump house	....	7, 200
Clarifier basins	....	45, 000
	606, 700	499, 200
Mechanical contract:		
Refractory furnaces and flues	204, 000	248, 400
Spray cooling chamber	221, 900	....
Steelwork	324, 000	228, 000
Insulation	133, 700	26, 500
Instrumentation	60, 000	42, 000
Installation of purchased equipment	132, 000	60, 000
Piping	....	58, 500
	1, 075, 600	663, 400
Purchased equipment:		
Fans and drives	135, 900	125, 900
Pumps and drives	....	19, 000
Air pollution control equipment	396, 000	337, 300
Clarifier equipment	....	64, 800
	531, 900	547, 000
Electrical contract: Power and lighting	195, 000	129, 000
Subtotal physical cost	2, 409, 200	1, 838, 600
Engineering and field supervision	169, 000	130, 000
Contingency	241, 000	185, 900
Escalation to December 1968	120, 500	92, 900
Total incremental physical cost	2, 939, 700	2, 247, 400

(*5*) **Markley, K. S.** *Fatty acids.* 2v. New York, Interscience Publishers, Inc., 1960.

(*6*) **Hunter-Wagner Engineering Division.** How we get our plastics/plastics world flow chart of major plastic materials. Kansas City, Black, Sivalls, and Bryson. 1 p.

(*7*) **Spencer, F. J.** Progress in polymers today. *Hydrocarbon Processing*, 45(7): 83–102, July 1966.

(*8*) **Sisler, H. H., C. A. Vander Werf, and A. W. Davidson.** *College chemistry, a systematic approach.* New York, The Macmillan Company, 1953. 623 pp.

(*9*) **Stenburg, R. L., R. P. Hangebrauck, D. J. von Lehmden, and A. H. Rose, Jr.** Field evaluation of combustion air effects on atmospheric emissions from municipal incinerators. *Journal of the Air Pollution Control Association*, 12(2): 83–89, Feb. 1962.

(*10*) **Kaiser, E. R.** Refuse composition and flue-gas analyses from municipal incinerators. *In* Proceedings, 1964 National Incinerator Conference, American Society Mechanical Engineers, New York, May 18–20, 1964. p. 35–52.

(*11*) **Shaw, J. T., and P. D. Green.** Oxidation of sulfur dioxide in air at 950° C: Cooperative influence of carbon monoxide and nitric oxide. *Nature (London)*, 211(5054): 1171–1172, Sept. 1966.

(*12*) **Hama, G. M., and L. C. Curley.** Corrosion of combustion equipment by chlorinated hydrocarbon vapors. *Air Engineering*, 7(4): 38–42, Apr. 1965.

(*13*) **Hangebrauck, R. P., D. J. von Lehmden, and J. E. Meeker.** Emissions of polynuclear hydrocarbons and other pollutants from heat-generation and incineration processes. *Journal of the Air Pollution Control Association*, 14(7): 267–278, July 1964.

(*14*) **Dernehl, C. U.** Health hazards associated with polyurethane foams. *Journal of Occupational Medicine*, 8(2): 59–62, Feb. 1966.

(*15*) **Dodson, V. N.** Ann Arbor case reports. I. Asthma and toluene di-isocyanate exposure. *Journal of Occupational Medicine*, 8(2): 81–83, Feb. 1966.

(*16*) **Jacobs, M. B.** Health aspects of air pollution from incinerators. *In* Proceedings, 1964 National Incinerator Conference, American Society Mechanical Engineers, New York, May 18–20, 1964. p. 128–131.

(17) Encyclopedia Britannica. Refuse analysis dirt and vacuum catch. v. 19. Chicago, Encyclopedia Britannica, Inc., 1944. p. 60.

(18) Furnas, C. C. *Rogers' industrial chemistry.* 2 v. New York, D. Van Nostrand Co., Inc., 1942.

(19) Kent, J. A. *Riegel's industrial chemistry.* New York, Reinhold Publishing Corp., 1962. 963 p.

(20) West, E. S., and W. R. Todd. *Textbook of biochemistry.* New York, The Macmillan Company, 1951. 1,345 p.

(21) Herbert, D. B. The nature of incinerator slags. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 191–194.

(22) Regis, A. J. X-ray spectrographic analysis of incinerator slags. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 195–198.

(23) Jens, W., and F. R. Rehm. Municipal incineration and air pollution control. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 74–83.

(24) Sax, N. I. Dangerous properties of industrial materials. New York, Reinhold Publishing Corp., 1957. 1,467 p.

BIBLIOGRAPHY

Clarke, L. *Manual for processing engineering calculations.* New York, McGraw-Hill Book Co., Inc., 1947. 438 p.

Manufacturing Chemists' Association, Inc. *Air pollution abatement manual; gas and vapor abatement.* Manual sheet P–11. Washington, Manufacturing Chemists' Association, Inc., 1953. 29 p.

Lenehan, J. W. Air pollution control in municipal incineration. *Journal of the Air Pollution Control Association,* 12(9): 414–417, Sept. 1962.

Hughson, R. V. Controlling air pollution. *Chemical Engineering,* 73(18): 71–90, Aug. 1966.

Phelps, A. H. What doesn't go up must come down. *Chemical Engineering Progress,* 62(10): 37–40, Oct. 1966.

Hemeon, W. C. L. Gas cleaning efficiency requirements for different pollutants. *Journal of the Air Pollution Control Association,* 12(3): 105–108, Mar. 1962.

O'Connor, C., and G. Swinehart. Baghouse cures stack effluent. *Power Engineering,* 65(5): 58–59, May 1961.

Stairmand, C. J. The design and performance of modern gas-cleaning equipment. *Institute of Fuel,* 29(181): 58–81, Feb. 1956.

appendix a

Table 10

REFUSE ANALYSIS: DIRT AND VACUUM CLEANER CATCH[1]

Dirt, soil =1.68% Vacuum cleaner catch = 0.84% 2.52% of refuse	Percent
Probable chemical constituents:	
Oxygen (O_2)	47.0
Silicon (Si)	27.0
Aluminum (Al)	8.0
Iron (Fe)	5.0
Calcium (Ca)	2.8
Magnesium (Mg)	2.8
Potassium (K)	2.8
Sodium (Na)	2.8
80 miscellaneous elements	1.7

[1] Abstracted from literature, cited in reference *17*.

Table 11

REFUSE ANALYSIS: GLASS AND CERAMICS[1]

Glass and ceramics=8.50% of refuse	Percent
Composition of typical glass:	
Silicon dioxide (SiO_2)	67.0–96
Boron oxide (B_2O_3)	1.0–16
Aluminum oxide (AlO3)	1.0– 4
Sodium oxide (Na_2O)	4.0–18
Calcium oxide (CaO)	0.3–13
Potassium oxide (K_2O)	0.1–12
Lead oxide (PbO)	15.0
Sulfur trioxide (SO_3)	0.4–00.7
Arsenic oxide (As_2O_3)	0.5– 1
Composition of ceramics:	
Silicon dioxide (SiO_2).	
Boron oxide (B_2O_3).	
Aluminum oxide (Al_2O_3).	
Sodium oxide (Na_2O).	
Calcium oxide (CaO).	
Potassium oxide (K_2O).	
Titanium dioxide (TiO_2).	
Chromium oxide (Cr_2O_3).	
Beryllium oxide (BeO).	
Zirconium oxide (ZrO_2).	
Tin oxide (Sn_2O).	
Magnesium oxide (MgO).	
Fluorides.	

[1] Abstracted from literature, cited in reference *18*.

Table 12

REFUSE ANALYSIS: METALS[1]

Metallic constituents: Metals=7.53% of refuse
Silicon (Si).
Carbon (C).
Nickel (Ni).
Chromium (Cr).
Magnesium (Mg).
Copper (Cu).
Aluminum (Al).
Tin (Sn).
Iron (Fe).
Manganese (Mn).
Molybdenum (Mo).
Cadmium (Cd).
Zinc (Zn).
Bismuth (Bi).
Sulfur (S).
Tungsten (W).
Mercury (Hg).
Arsenic (As).
Vanadium (V).
Antimony (Sb).
Phosphorus (P).
Beryllium (Be).

[1] Abstracted from literature, cited in reference *18*.

Table 13

REFUSE ANALYSIS: WOOD, PAPER PRODUCTS, PLANT AND FOOD WASTES[1]

Wood and balsam spruce = 2.52%
Wood (paper) products = 56.01%
Food wastes = 9.24%
Plants and grass = 7.56%
75.33% of refuse

Probable constituents, composition:	
Cellulose	Carbohydrates.
Pentosans	
Monosaccarides	
Oligosaccarides	
Polysaccarides	
Lipids—fats	
Proteins (polyamides)	
Ash:	Book & magazines (24.05% ash). Cardboard (7.79% ash). Mixed paper (6.55% ash). Newsprint (3.93% ash).
SiO_2	
Al_2O_3	

[1] Abstracted from literature, cited in references *10*, *18*, *19*, and *20*.

PRECEDING PAGE BLANK

TABLE 14

REFUSE ANALYSIS

PLASTICS[1]

Plastics=3.50% of refuse	
Type	*Source*
Acrylonitrile butadiene styrene	Shoe heels, appliances.
Cellulose acetate	Pens, handles, frames, combs, toys.
Cellulose acetate butyrate	Pens, handles, frames, combs.
Cellulose nitrate	Pens, pencils.
Melamine formaldehyde	Bottlecaps, buttons.
Polyethylene	Film, flexible bottles, containers.
Polyvinyl dichloride	Bottles, toys.
Urea formaldehyde	Bottlecaps, buttons, dinnerware.
Urethane	Coatings, laminates, adhesives.
Polymethyl methacrylate	Buttons.
Polypropylene	Fibers, packaging, films, appliances.
Polystyrene	Combs, buttons, containers, toys, housewares.
Polyvinyl acetate	Records.
Polyvinyl chloride	Films, bottles, toys.

[1] Abstracted from literature, cited in references *6* and *7*.

TABLE 15

REFUSE ANALYSIS: RAGS[1]

Rags=0.84% of refuse	Composition
Cotton	Cellulose, sulfur.
Nylon	Diamine, diacarboxylic acid, caprolactam.
Silk	Complex polyamides.
Orlon and Acrilan	Acrylonitrile.
Dynel	Copolymer of acrylonitrile and vinyl chloride.
Dacron	Complex polyester.
Rayon	Cellulose acetate, ethyl cellulose, viscose rayon.
Wood	Protein—complex polyamide.

[1] Abstracted from literature, cited in references *18* and *19*.

TABLE 16

REFUSE ANALYSIS: PAINTS AND OILS[1]

Paints, oils, removers=0.84% of refuse	Paints, oils, removers=0.84% of refuse
Composition:	
White lead.	Methylene chloride.
Titanium dioxide (TiO_2).	Maleic anhydride.
Zinc oxide (ZnO).	Phthalic anhydride.
Zinc sulfide.	Polystyrene.
Calcium chloride ($CaCl_2$) and other hygroscopic salts.	Phenol. Cresols. Cresylic acid.
Chromium (Cr).	Xylenols.
Alkyd and phenol aldehydes.	Acrylates. Polyamides.
Acetone.	Urea.
Methanol.	Vinyl.
Benzene.	

[1] Abstracted from literature, cited in references *18* and *19*.

TABLE 17

REFUSE ANALYSIS: LEATHER[1]

Leather=0.42 of refuse	Composition	Percent
Collagen	Amino acids	95
Glycogen	Animal starch	5
Glycerides	Natural fats—esters of glycerin.	

[1] Abstracted from literature, cited in references *18* and *19*.

TABLE 18

REFUSE ANALYSIS: RUBBER[1]

Rubber=0.42% of refuse	Percent	
Composition–natural:		*Composition (types)—synthetics:*
Proteins—amino acids	2.0	Butadiene polymers.
Fatty acids, esters	1.0	Chloroprene polymers.
Quebrachital	1.0	Isobutene polymers.
Inorganic salts	0.4	Organic polysulfides.
Rubber hydrocarbons	35.0	Plasticized vinyl chloride.
Water	60.0	Butadiene +styrene.
Sulfur	0.6	Butadiene+ acrylonitrile.
		Ethylene dichloride.
		Isobutylene+ isoprene.
		Isobutylene+ butadiene.

[1] Abstracted from literature, cited in references *18* and *19*.

TABLE 19

REFUSE ANALYSIS: MISCELLANEOUS[1]

Miscellaneous items of refuse	Composition
Developers	Nitrophenols, nitrobenzene, hydroquinone.
Dyestuff	Carbazole, phenanthraquinone, anthraquinone, naphthalene sulfonic acids, salicylic acid, benzaldehyde, toluides, xylenes, halogenated benzene, aniline salts, dimethylaniline, aniline.
Insecticides	Crude naphthalene, nitro napthalene, halogenated benzene.
Preservatives	Anthranilic acid.
Flavorings and perfumes	Benzoic acid, benzaldehyde.

[1] Abstracted from literature, cited in references *18* and *19*.

TABLE 20

DATA ON FATTY ACIDS[1]

Common name	Classification	Structure	Occurrence
Formic acid	Saturated	HCOOH	Obtained by pyrolysis of many organic substances.
Acetic acid	Saturated	CH_3COOH	Occurs both free and combined in the form of esters of various alcohols in many plants.
Palmitic acid	Saturated	$C_{15}H_{13}COOH$	Found in vegetable and animal fats.
Stearic acid	Saturated	$C_{17}H_{35}COOH$	Predominant component of body fats of animals. Small amounts of fruit flesh and seed fats.
Oleic acid	Unsaturated (*9*, *10*)	$C_{17}H_{33}COOH$	Predominant fatty acid of natural fats. Found in every plant and animal fat. Comprises 50% or more of the fatty acids.
Palmitoleic acid	Unsaturated (*9*, *10*)	$C_{15}H_{29}COOH$	Widely distributed in nature. Second to oleic in frequency of unsaturated acids.

[1] Abstracted from literature, cited in reference *5*.

Table 21
DECARBOXYLATION OF FATTY ACIDS[1]

Kind of fatty acid or derivative	Temperature	Additional conditions	Products
Normal lower fatty acids		Ordinary pressures	Readily distilled, yields fatty acid.
stearic	300° C. (6 hours)	Vapor state in presence of SiO_2, TiO_2, CuO, ZnO.	6–7% Ketones, 93–94% Fatty acids.
stearic	300° C. (6 hours)	In presence of CdO	13% Ketones, 87% Fatty acids.
stearic	300° C. (6 hours)	In presence of iron oxides, Al_2O_3, MgO.	17–24% Ketones, 76–83% Fatty acids.
Salts of saturated acids:			
magnesium stearate	350° to 400° C		80% Acetone soluble material: 80% fatty acids.
calcium stearate	450° C		30% Acetone soluble material: 30% fatty acids.
Monoesters: ethyl stearate	300° C		Stearic acid + ethylene.

[1] Abstracted from literature, cited in reference *5*.

Table 22
AMOUNT OF POLYNUCLEAR HYDROCARBONS, INCINERATOR EFFLUENT GAS[1]

	Micrograms/gm. of particulate
Benzo(*a*)pyrene	0.016
Pyrene	1.9
Benzo(*e*)pyrene	.08
Coronene	.06
Fluoranthene	2.2
Benzo(*a*)anthracene	.09

[1] Data on a 250 ton/day municipal incinerator (breeching before settling chamber) when burning rubber tires, abstracted from literature, cited in reference *13*.

Table 23
HALOGENATED HYDROCARBONS[1]

Generic name	Chemical formula
Trichloroethylene	C_2HCl_3.
Perchloroethylene	C_2Cl_4.
Carbon Tetrachloride	CCl_4.
Methylene Chloride	CH_2Cl_2.
Methyl Chloroform	CH_3CCl_3.
"Freon" F–12	CCl_2F_2.
"Freon" F–114	$C_2Cl_2F_4$.
"Freon" F–11	CCl_3F.
"Freon" F–21	$CHCl_2F$.

[1] Tabulation of the types of halogenated hydrocarbons used in pressurized cans abstracted from literature, cited in reference *12*.

Table 24
ANALYSIS OF INCINERATOR SLAGS[1]

	Wet chemical analysis run on slag (percent)		
	Sample B	Sample D	Sample F
Silicon dioxide (SiO_2)	43.01	49.91	45.99
Aluminum oxide (Al_2O_3)	24.85	8.73	21.47
Iron oxide (Fe_2O_3)	6.00	12.78	7.78
Titanium oxide (TiO_2)	3.31	2.40	3.00
Calcium oxide (CaO)	9.28	11.03	9.5
Magnesium oxide (MgO)	2.47	2.54	2.65
Sodium oxide (Na_2O)	3.28	3.31	3.16
Potassium oxide (K_2O)	.73	2.27	1.09
Phosphorus oxide (P_2O_5)	2.05	2.40	2.00
Barium oxide (BaO)	.66	.45	.62
Zinc oxide (ZnO)	1.17	2.49	.46

[1] Data on nature of incinerator slags abstracted from literature, cited in reference *21*.

Table 25
ANALYSIS OF INCINERATOR SLAGS[1]

Slags	Percent
Silicon dioxide (SiO_2)	40–52
Aluminum oxide (Al_2O_3)	8–25
Phosphorus oxide (P_2O_5)	2.0–2.5
Potassium oxide (K_2O)	0.5–2.5
Calcium oxide (CaO)	9–11.5
Iron oxide (Fe_2O_3)	5.5–8.5
Titanium oxide (TiO_2)	2.2–3.5
Zinc oxide (ZnO)	0.25–2.75

[1] Data on x-ray spectographic analysis of incinerator slags abstracted from literature, cited in reference *22*.

TABLE 26
ANALYSIS OF INCINERATOR EFFLUENTS[1]
[Percent]

Element	Test run no. 6			Test run no. 8
	Stack effluent	Collector catch	Residue	Stack effluent
Silicon	5+	10+	10+	5+
Manganese	0.1–1.0	0.1–1.0	0.1–1.0	0.1–1.0
Chromium	0.1–1.0	0.01–0.1	0.01–0.1	0.1–1.0
Nickel	1–10	0.001–0.01	0.001–0.01	10+
Copper	0.1–1.0	0.01–0.1	0.01–0.1	0.1–1.0
Vanadium	0.001–0.01	0.01–1.0	0.01–0.1	0.001–0.01
Iron	0.5–5.0	0.5–5.0	1–10	0.1–1.0
Tin	0.05–0.5	0.05–0.5	0.1–1.0	0.001–0.01
Aluminum	1–10	1–10	1–10	0.1–1.0
Zinc	1–10	1–10	0.1–1.0	1–10
Magnesium	1–10	1–10	1–10	1–10
Titanium	0.5–5.0	0.5–5.0	0.5–5.0	0.5–5.0
Silver	0.001–0.01	0.001–0.01	0.001–0.001	–0.0001
Boron	0.01–0.1	0.01–0.1	0.01–0.1	0.01–0.1
Barium	0.1–1.0	0.1–1.0	0.1–1.0	0.1–1.0
Beryllium	0.001–0.01	0.001–0.01	–0.001	–0.0001
Calcium	1.0+	10+	10+	10+
Sodium	1–10	0.5–5.	0.1–1.0	1–10
Lead	0.01–0.1	0.1–1.0	0.1–1.0	0.05–0.5

[1] Data on spectographic analysis elements reported in percent ashed material abstracted from literature, cited in reference 23.

TABLE 27
ANALYSIS OF FLY ASH[1]
[Percent]

	Collected in system	Emitted from stack
Silicon as SiO_2	49.5	36.3
Aluminum as Al_2O_3	22.9	25.7
Iron as Fe_2O_3	6.3	7.1
Calcium as CaO	8.8	8.8
Magnesium as MgO	2.2	2.8
Sodium as Na_2O Potassium as K_2O	6.0	10.4
Titanium as TiO_2	1.3	.9
Sulphur as SO_3	3.0	8.0

[1] Data on fly ash analyses (weight percent) abstracted from literature, cited in reference *10*.

TABLE 28
SOURCES OF AMMONIA IN EFFLUENT GASES[1]

	Chemical	Symbol
Plastics:		
Acrylonitrile butadiene styrene.	Hexamethylene diamine.	NH_3
Urea formaldehyde	Urea	NH_3+CO_2
Urethane (polyurethanes).	Toluene diisocyanate.	NH_3
Polymethyl methacrylate		NH_3
Polystyrene	Hexamethylene diamine.	NH_3
Wood, wood products, food wastes, plants, grass:		
Proteins (polyamides)	Amino acids	NH_3

[1] Abstracted from literature, cited in references *6*, *7*, and *20*.

TABLE 29

TOXIC AND CORROSIVE CHARACTERISTICS OF ORGANIC SUBSTANCES

Name	Form	Toxicity [1]	Corrosive property [2]
Organic acids:			
formic	Gas		Weakly acidic.
acetic	Gas & particulate.	2	
palmitic	do.		
stearic	do.	1	
oleic	do.	1	
palmitoleic	do.		
Aldehydes:			
formaldehyde	Gas	3	
acetaldehyde	do.		
Esters:			
methyl acetate	do.	2	
ethyl acetate	do.	2	
ethyl stearate	do.		
CO_2	do.	1	
CO	do.	3	
Phosgene, toluene diiosocyanate.	do.	3	
Halogenated hydrocarbons	do.	(3)	
Polynuclear hydrocarbons	do.	(4)	

[1] Toxicity is designated as follows (*24*): 0, none; 1, slight; 2, moderate; 3, high; u, unknown.

[2] Corrosive properties are reported as acidic or basic (*8*).

[3] See table 30.

[4] See table 31.

TABLE 30

TOXIC AND CORROSIVE CHARACTERISTICS, HALOGENATED HYDROCARBONS IN PRESSURIZED CANS [1]

Name [2]	Threshold limit values (p.p.m.)	Odor Threshold (p.p.m.)	Air concentration corrosion [3] (p.p.m.)
Trichlorethylene	100	50	5–23
Perchlorethylene	100	50	20–75
Carbon tetrachloride	10	25	[4] 5–50
Methylene chloride	500	25 to 50	50
Methyl chloroform	350	Below threshold limit value.	5–50
Freon® 12	1,000	Almost odorless	1–100
Freon® 114	1,000	do.	1–100
Freon® 11	1,000	do.	1–100
Freon® 12	1,000	do.	1–100

[1] Abstracted from literature, cited in reference *12*.

[2] See table 23 for chemical formula.

[3] If decomposed into corrosive products.

[4] Estimated.

TABLE 31

TOXIC AND CORROSIVE PROPERTIES, POLYNUCLEAR HYDROCARBONS [1]

Compound	Biological activity	Corrosive property
Benzo(*a*)pyrene	3	
Pyrene	0	
Benzo(*e*)pyrene	1	
Coronene	0	
Fluoranthene	0	
Benz(*a*)anthracene	1	

Code: 3, active; 2, moderate; 1, weak; 0 inactive.

[1] Abstracted from literature, cited in reference *13*.

TABLE 32

TOXIC AND CORROSIVE CHARACTERISTICS, INORGANIC PARTICULATES

Chemical	Toxicity [1]	Corrosive property [2]
Silicon dioxide, SiO_2	3	Very weakly acidic.
Sodium oxide, Na_2O	3	Strongly basic.
Aluminum oxide, Al_2O_3	1	Slightly basic.
Potassium oxide, K_2O	3	Strongly basic.
Magnesium oxide, MgO	2	Mildly basic.
Zinc oxide, ZnO	1	Amphoteric [3].
Titanium dioxide, TiO_2	1	Mildly acidic.
Iron oxide, Fe_2O_3	1	Strongly basic.

[1] Toxicity is designated as follows (*24*): 0, none; 1, slight; 2, moderate; 3, high.

[2] Corrosive properties are reported as acidic or basic (*8*).

[3] Amphoteric: both acidic and basic.

TABLE 33

TOXIC AND CORROSIVE CHARACTERISTICS, INORGANIC GASES

Chemical	Toxicity [1]	Corrosive property [2]
Sulfur oxides, SO_2, SO_3	3	Strongly acidic.
Ammonia, NH_3	3	Basic.
Nitrogen dioxide, NO_2	3	Acidic.
Chlorine and hydrogen chloride.	1	Strongly acidic.
Fluorine and hydrogen fluoride	3	Do.

[1] Toxicity is designated as follows (*24*): 0, none; 1, slight; 2, moderate; 3, high; U, unknown.

[2] Corrosive properties are reported as acidic or basic (*8*).

TABLE 34

EFFECT OF AIR FLOW ON NO_2 CONCENTRATION IN FLUE GAS[1]

Underfire air (%)	Excess air (%)	Gas temp. (secondary chamber) °Fahrenheit	NO_2, lbs 1,000 lbs dry flue gas (converted to 50% excess air)
20	190	1,750	0.33
50	180	1,790	.27
80	190	1,930	.22
100	150	1,960	.20

[1] Data on summary of average emission from 250-ton per day incinerator abstracted from literature, cited in reference *9*.

TABLE 35

EFFECTS OF AIR FLOW ON ALDEHYDE FORMATION[1]

Underfire air (%)	Excess air (%)	Temporary secondary chamber (° Fahrenheit)	Formaldehyde (pounds/1,000 lbs of dry flue gas converted to 50 percent excess air) (before H_2O spray scrubber)
20	190	1,750	3.9×10^{-4}
50	180	1,790	2.8×10^{-4}
80	190	1,930	1.7×10^{-4}
100	150	1,960	1.7×10^{-4}

[1] Data on a 250-ton-per-day incinerator abstracted from literature, cited in reference *9*.

TABLE 36

SOLUBILITY OF GASEOUS POLLUTANTS IN WATER

	Solubility in water[1]
Carbon monoxide (CO)	Slightly.
Carbon dioxide (CO_2)	Moderately.
Ammonia (NH_3)	Very soluble.
Sulfur dioxide (SO_2)	Slightly.
Sulfur trioxide (SO_3)	Very soluble.
Nitrogen dioxide (NO_2)	Soluble.
Hydrogen chloride (HCl)	Very soluble.
Hydrogen fluoride (HF)	"
Fatty acids	Soluble (short-chain).
Aldehydes	Soluble.
Esters	Insoluble.
Hydrocarbons	"

[1] Abstracted from literature, cited in reference *8*.

control laboratory

ABSTRACT

THIS REPORT presents itemized lists of instrumentation and laboratory equipment and their estimated installed costs. This equipment was selected to permit normal monitoring of plant operation and to aid in the performance of tests for development of incinerator design and operating techniques. References to existing test procedures are presented to aid in the proper application of the equipment items suggested.

INTRODUCTION

CONTROL OF THE OPERATION of a modern continuous feed incinerator plant requires instrumentation that will indicate and record for the plant operators and supervisors, the existing operating conditions and any deviations from normal. Further development of incinerator operating and design techniques will be expedited by special laboratory equipment and test facilities that will permit a complete investigation and evaluation of all of the variables of refuse composition, furnace operation, flue gas conditions, process water contamination, and residue composition.

The equipment required to instrument an incinerator plant and equip laboratories for research and development work has been divided into four categories, as follows: Group I, indicating and recording equipment for incinerator operation; group II, physical laboratory equipment; group III, chemical laboratory equipment; and, group IV, monitoring equipment for test and development studies.

An itemized list of equipment is presented for each of these groups including estimates of installed costs and space requirements.

SUMMARY AND RECOMMENDATIONS

The instruments listed in group I (indicating and recording equipment for incinerator operation) are essential to good plant operation and their installation is recommended in the proposed No. 5 Incinerator plant for the District of Columbia.

The balance of the instruments and laboratory equipment listed in this report have been selected to permit complete analyses and testing of the incinerator plant operation. There is currently a lack of complete test data on municipal incinerator operation. The installation of this equipment is recommended so that complete test data can be obtained for use in improving municipal incinerator practices. The estimated costs for the various groups of equipment installed, and the laboratory space, are listed in table 37.

TABLE 37

ESTIMATED INSTALLED COSTS FOR EQUIPMENT AND LABORATORY SPACE

Group	Equipment and space	Cost
I	Indicating and recording for incinerator operation	$158,000
II	Physical laboratory	11,900
	Physical laboratory space	22,500
III	Chemical laboratory	73,955
	Chemical laboratory space	50,000
IV	Monitoring	106,320
	Master control room for monitoring equipment	25,000
	Subtotal	289,675
	Total cost of instrumentation and laboratory equipment	447,675

GROUP I

Indicating and Recording Equipment for Incinerator Operation

The operation of a conventional incinerator furnace of modern continuous feed design can usefully employ a more elaborate system of instrumentation than the older batch feed type units. This additional equipment is justified if the operation of the plant is to be maintained at design conditions with optimum burnout of the refuse and minimum air pollution. The

PRECEDING PAGE BLANK

instruments tabulated below will monitor plant operating conditions and sound alarms if operating conditions deviate too far from normal or if potential or actual equipment failure is indicated.

We recommend the installation of the following indicating instruments on a control panel at each furnace unit:

	Equipment list price	*Installation, including overhead*	*Total*
Draft gages indicating pressures (or drafts) of all air supply systems, underfire air compartments, furnace, air pollution control equipment inlet and outlet, induced draft fan inlet and stack....................	$800	$1, 600	$2, 400
Bourdon tube pressure gages for water and compressed air supplies to the unit...........	600	550	1, 150

We recommend the installation of the following indicating-recording instruments on the control panel at each furnace unit:

	Equipment list price	*Installation, including overhead*	*Total*
Smoke density recorder..........	$1, 590	$515	$2, 105
Temperature recorders for furnace and stack temperatures........	1, 975	925	2, 900
Counter recorder for number of buckets charged each furnace...	400	170	570

The following additional recorders should be provided for installation on a supervisor's panel:

	Equipment list price	*Installtion, including overhead*	*Total*
Ambient air temperature........	$630	$500	$1, 330
Wind speed and direction.......	2, 500	1, 800	4, 300

The following indicating-recording-controlling units are recommended for installation on the control panel at each furnace unit:

	Equipment list price	*Installtion, including overhead*	*Total*
Furnace draft recorder controller.	$2, 725	$1, 275	$4, 000
Flue gas temperature recorder controller..................	3, 600	2, 000	5, 600
Induced draft fan motor overload controller..................	2, 100	650	2, 750
Remote airflow damper controller......................	350	350	700

We recommend the installation of multiple alarm units including horns and lights for all of the critical items in furnace operation where damage to equipment or loss of production might occur if their operating conditions change without notice. Fifteen to twenty alarm points normally are monitored at each furnace. Examples of such alarm points are high and low furnace temperatures, high furnace pressure (loss of furnace draft), high and low stack temperatures, high ashpit temperature, high smoke density, high cooling water temperatures, low water pressure, high ampere loading of induced draft fan, low compressed air pressure, and stoker failure.

	Equipment list price	*Installation, including overhead*	*Total*
Monitoring 15 alarm units for each furnace.................	$700	$650	$1, 350

The installation of a total of six television cameras and three monitors is recommended. One camera would be in each of the four furnaces and two cameras would be mounted on the charge floor. All monitors would be located at the central control room.

	Equipment list price	*Installation, including overhead*	*Total*
Six television cameras, including air-cooled furnace housing, protruding air-purged furnace lenses, and water-cooled air supply compressor.............	$48, 000	$9, 000	$56, 000
Three 14-inch television monitors.	1, 670	600	2, 270

It is estimated that the indicating and recording equipment tabulated above for group I could be installed, piped, and wired on appropriate panels for approximately $158,000 for a four-furnace plant.

GROUP II

Physical Laboratory Equipment

This section covers the equipment required for the collection, sample preparation, and physical analyses of samples of refuse, ash residue, fly ash, and furnace slag.

We referred to ASTM Standard: D 271-64, *Standard Methods of Laboratory Sampling and Analysis of Coal and Coke*, for equipment selection and laboratory procedures for refuse analysis (*1*).

These ASTM procedures provide for the determination of moisture content, ash, volatile matter, fixed carbon, sulphur, ash fusibility, ultimate analysis, and heating value of coal and coke. They may be used as a guide for the development of refuse test procedures pending new standards developed specifically for incinerator plant work. Chemical tests described are covered in the group III equipment section of this report.

The collection and size reduction of a composite refuse sample is difficult to accomplish in a reproducible manner. Procedures similar to ASTM Standard D 2013–65 T (2) may be followed; however, most test operators resort to first separating a large sample of refuse into each of its components. These components are then individually weighed and analyzed and the composite sample analysis determined by weighted additions of the analyses of the individual components.

To analyze a typical composite refuse sample, the following procedure would be employed: A refuse sample representative of the furnace charge is spread on tared (weighed) pans, weighed, and air dried at room temperature, or in a special drying oven at 10° C. to 15° C. above room temperature, and weighed again. The drying is continued until the loss in weight is not more than 0.1 percent per hour. The sample is then put through an initial shredder and a final shredder to reduce the pieces of refuse to a much finer consistency. A riffle sampler is used for homogenizing and separating a larger sample into several similar smaller ones.

Several different analyses are performed on these smaller samples. A drying oven is used to determine the weight percent of water and volatile matter, a low temperature muffle furnace for weight percent carbon and ash, and an adiabatic calorimeter for determining the heat of combustion of any solid or liquid material that can be completely burned in oxygen.

Instruments and equipment prices for physical preparation and analysis of refuse, ash, and furnace slag are based on the catalogs of scientific laboratory and industrial apparatus suppliers (3–5).

The equipment shown in table 38 is required for refuse sample preparation and analysis.

The analysis of slag and flyash is desirable to develop methods for the control of slag formation. Samples should be checked for ash softening temperature and complete chemical composition. Detailed procedures are outlined in ASTM Standard D 1857–64 T (*6*) which may be used as a guide, pending development of incinerator test standards. For slag and ash sample preparation, the additional equipment shown in table 39 is required.

TABLE 38

LABORATORY EQUIPMENT FOR REFUSE SAMPLE ANALYSIS

	Equipment list price	Installation, including overhead	Total
Initial shredder with heavy-duty rotor blades driven by a 3-hp. electric motor	$550	$400	$950
Final shredder with ½-hp. electric motor	930	90	1,020
Scale having a 5-kg. capacity and 0.5-gm. sensitivity	100	....	100
Riffle sampler with stainless steel hopper containing 24 chutes with ⅜″ x 4.5″ openings	145	....	145
Drying oven-mechanical convection, electric, up to 260° C., bench type	430	100	530
Low temperature electric muffle furnace with self-contained voltage input adjuster and indicating pyrometer on the panel, with a 1,200° C. range	160	100	260
Analytical balance having a 160-gm. capacity and 0.1-mg. sensitivity	770	....	770
Desiccators, 4-glass vacuum type with desiccant	55	....	55
Adiabatic oxygen bomb-type calorimeter with electric water heater	1,280	....	1,280
Galvanized iron pans approximately 18″ x 18″ x 1.5″	15	....	15
Porcelain capsules with flat aluminum covers	10	....	10
Galvanized iron or tin can containers with air-tight friction or screw tops with rubber gaskets	30	....	30

TABLE 39

LABORATORY EQUIPMENT FOR SLAG AND ASH SAMPLE PREPARATION

	Equipment list price	Installation, including overhead	Total
Bandsaw with abrasive blade for cutting samples to size	$480	$220	$700
Power crusher with 2-hp. motor	600	250	850
Motor-driven pulverizer with 6″-diameter grinding discs	530	220	750

For ash and slag softening temperature determinations, the additional equipment shown in table 40 is required.

The equipment required for chemical analysis of refuse, residue, ash, and slag is described in more detail with the group III equipment of this report.

TABLE 40

LABORATORY EQUIPMENT FOR SLAG AND ASH TEMPERATURE DETERMINATION

	Equipment list price	Installation, including overhead	Total
Brass cone molds suitable for making ash cones ¾" in height and ¼" in width at each side of the base	$25	....	$25
High temperature electric muffle furnace with indicating pyrometer controller and silicon carbide heating elements providing uniform temperature to a maximum of 2,700° F	1, 350	$200	1, 550

In selecting equipment for flue gas sampling for moisture concentration and particulates, gaseous and soluble contaminants, we consulted the following sources: A paper by Jacobs, Braverman, Hochheiser, and Ettinger (*7*); a paper by F. R. Rehm (*8*); the ASME Test Code PTC 21–1941, (*9*); the ASME Test Code PTC 27–1957 (*10*); and Bulletin WP–50 of the Western Precipitation Corp. (*11*).

The first paper mentioned above details the methods developed in a collaborative sudy by the Bureau Laboratory, Department of Air Pollution Control, city of New York and the Engineering Research Division of New York University, for the sampling and analysis of flue-fed incinerator effluent gases. Comparatively uncomplicated apparatus are described for the sampling and analysis of inorgainic gaseous components such as nitrogen oxides, sulfur oxides, hydrogen sulfide, ammonia, carbon monoxide, carbon dioxide, and oxygen; of organic components such as organic acids, esters, aldehydes, benzene, phenols; and for smoke density determination.

Connections are made in the flue for a thermocouple, Pitot tube, and several sampling probes. To facilitate sampling, a two-manifold arrangement is used so that many substances can be sampled for simultaneously with a single probe. One manifold is attached to the flue probe and the other to the vacuum line. Trapping devices such as impingers or fritted glass bubblers are attached with flexible tubing to the manifolds.

Filtering devices such as a cyclone precipitator and special dust filters should be located in front of the measuring and exhausting devices. They should have a minimum filtering efficiency of 99 percent by weight for the fly ash in the flue gases. An electric heater is required for the dust filter case to prevent wetting of the dust filter by condensed moisture. A cooling water condenser with a graduated condensate collector should be located immediately after the filtering devices for moisture concentration measurements.

Another flue opening can be used for taking samples for the Orsat analysis apparatus to determine the concentration of carbon dioxide, oxygen, and carbon monoxide.

The equipment referred to in table 41 is recommended for field sampling of flue gases.

TABLE 41

LABORATORY EQUIPMENT FOR FLUE GAS SAMPLING

	Equipment list price	Installation, including overhead	Total
Dust sample collectors, 4 graduated impinger type	$120	$0	$120
Dust filtering unit with filter case and electric heater	150	0	150
Stainless steel condenser	300	0	300
Condensate collector	25	0	25
Portable dry gas meter for measuring flue gas flow rate with manometer and thermometer connected to inlet chamber	200	0	200
Two dust sampling cases each with 10 graduated impinger sampling tubes, stoppers, and rubber tubing	200	0	200
Vacuum pump with 1/3 hp. electric motor	150	0	150
Draft gage	40	0	40
Pitot tubes	1, 300	0	1, 300
Portable indicating, high resistance pyrometer designed for laboratory check work	175	0	175
Portable Orsat apparatus with 4 absorption pipettes and provision for electrical heating of a replaceable platinum wire coil	200	0	200

Solid samples collected with the above equipment must be further checked for particle size distribution. Equipment and procedures required for this are described in more detail with the group III equipment of this report.

It is estimated that the equipment tabulated for group II of this report can be purchased and installed for approximately $11,900.

Approximately 500 square feet of floor space would be required for the installation of this equipment including working space for physical tests. It is estimated that the addition of this space to the incinerator plant, complete with laboratory furniture, sinks, closets, electrical lighting and power outlets, plumbing fixtures, piping and air conditioning, would cost $22,500.

GROUP III

Chemical Laboratory Equipment

This section covers equipment required for the chemical analysis of samples collected or prepared with the equipment listed under group II, physical laboratory equipment.

Presented in this section is the chemical laboratory equipment recommended for complete analysis of refuse, slag, residue, fly ash, water, and flue gas. In general, this equipment is of a more sophisticated and delicate nature than that of the physical laboratory. Therefore, these two laboratories will be separated from each other and any delicate equipment usually used in physical testing will be located in the chemical laboratory. Examples of such equipment are the microscopic and photographic apparatus required for particulate determination of gas and water samples.

Instrument and equipment costs were obtained from the catalogs used for group II items, as well as direct quotations from individual equipment manufacturers.

The ASME Test Code PTC 28–1965, (*12*) and ASTM Designation: E11–61, (*13*) were referred to for equipment for particulate analysis studies. Among the test procedures described in these references are specific gravity, particle size distribution, bulk electrical resistivity, bulk density, and moisture content. The equipment recommended for gas and water sample particulate determinations is tabulated in table 42.

For equipment and methods used in refuse sample ultimate analysis, reference was made to ASTM Standard D 271–64 (*1*) and work by Etzel and Bell (*14*). As previously reported, the procedures required

TABLE 42

LABORATORY EQUIPMENT FOR PARTICULATE DETERMINATIONS

	Equipment list price	Installation, including overhead	Total
Analytical balance having a 160-gm. capacity and 0.1-mg. sensitivity	$770	....	$770
Drying oven—mechanical convection, electric, up to 260° C., bench type	430	$100	530
Set of 23 sieves of 8″ diameter recommended as International (ISO) Standards ranging from 90.5 mm. to 44.0 mμ	270	....	270
Electrical sieve shaker with ¼ hp. motor and vibration regulation control	700	....	700
Photobinocular microscope with graduated mechanical stage, continuously variable magnification flat field achromatic system, and high intensity illuminator	1,080	....	1,080
Three interchangeable camera accessories for the photobinocular microscope:			
35-mm. camera	175	....	175
3¼″ x 4¼″ Polaroid filmpack	110	....	110
4″ x 5″ platemaking camera	150	....	150
Scale having a 5-kg. capacity and 0.5 gm. sensitivity	100	....	100
Chemical centrifuge with 7-step speed control rheostat and stainless steel basket and draining chamber	485	....	485
Filtering and dissolving porcelain cone filter, case of 3 with 2-mm. hole perforated coors	30	....	30
Turbidimeter with opal glass light source, reflector adjustable slit, apertured mirror, and specimen tube for measuring suspended matter or colloids in water	355	....	355
Le Chatelier flask for specific gravity determination of particulates, per case of 2	25	....	25
Constant temperature water bath with electric heating and agitation	300	....	300
High-voltage conductivity cell for determination of bulk electrical resistivity with an 0 to 15 kv. voltage output at currents up to 1 milliampere	500	....	500

TABLE 42—*Continued*

LABORATORY EQUIPMENT FOR PARTICULATE DETERMINATIONS—Con.

	Equipment list price	Installation, including overhead	Total
Electric oven, temperature and humidity controlled for containing the high-voltage conductivity cell	$1,000	....	$1,000
Desiccator (4) glass vacuum type with desiccant	55	....	55
Combustion crucibles with covers (6 with 20-milliliter-capacities each)	80	....	80
Bahco micro particle size classifier	2,895	200	3,095

to obtain a reproducible representative sample have not been adequately developed and most operators separate the refuse into individual components for analysis. Further test work is recommended to develop suitable refuse sampling and test procedures.

To determine the total percentages of carbon and hydrogen present a sample is weighed and then burned in a closed system with the products of combustion being fixed in an absorption train after complete oxidation and purification from interfering substances.

An automatic nitrogen analyzer was selected for nitrogen concentration determination instead of choosing apparatus for the wet chemical Kjeldahl-Gunning method in order to decrease the analysis time required and increase the accuracy of the results.

For sulfur analysis, an electric oxygen bomb type apparatus is suggested. Samples are burned in an atmosphere of compressed oxygen so that all hydrocarbons are oxidized to carbon dioxide and water, and all sulfur compounds are converted to sulfur oxides. These oxides are absorbed in a water chamber at the bottom of the bomb and standard quantitative methods are then used to determine the amount of sulfur present.

The equipment recommended for chemical analysis of refuse samples is tabulated in table 43.

Chemical analysis of slag, ash, and water samples can best be performed in a well equipped syectrographic laboratory.

Work by Regis (*15*) demonstrated that the analysis of slag type materials by instrumental methods gives the desired accuracy and requires a fraction of the time needed for analysis by wet chemical methods.

TABLE 43

LABORATORY EQUIPMENT FOR REFUSE CHEMICAL ANALYSIS

	Equipment list price	Installation, including overhead	Total
Automatic combustion unit with 3 electrically heated furnace sections, individually controlled and having a maximum continuous furnace temperature of 950° C	$1,750	....	$1,750
Rate of flow meter and regulator	35	....	35
Water absorber, 2 required, both containing solid dehydrating reagent	40	....	40
Carbon dioxide absorber containing solid absorbing agent	20	....	20
Automatic nitrogen analyzer, complete with thermometer, 100 aluminum combustion boats, copper tubing assembly, accessories, and chemical reagents	2,500	....	2,500
Sulfur apparatus, double-valve, oxygen-bomb type with water bath, ignition unit, oxygen connection, gages, valves, 6 stainless steel fuel capsules, and 100 gelatin capsules	560	....	560

Characteristic K alpha radiation was used in the spectrograph to analyze incinerator slag samples of diverse chemical compositions for Al_2O_3, SiO_3, K_2O, CaO, P_2O_5, Fe_2O_3, TiO_2 and ZnO. Determination of lighter elements such as chlorine, phosphorus, sulfur, and bromine is now possible due to recent technological improvements.

The vacuum x-ray type of spectrograph is more applicable for analyzing compounds of higher concentration in a specific sample while the arc emission type of spectrograph gives more accurate analysis of trace quantities. The former of these types is more desirable for the present application.

It is estimated that a complete installed vacuum x-ray spectrographic laboratory consisting of a sample grinder, sample hydraulic press, sample pellet dies, power source unit, vacuum spectrograph x-ray tube system, electronic direct reading detector, and film diffraction study facilities would cost $40,000.

A series of wet testing procedures for ash residue analysis by the Drexel Institute of Technology's environmental engineering department were also reviewed for determinations not applicable to x-ray spectrographic analysis (*16*).

The method for determining the lipid concentration where lipids are defined as "any of various substances including fats, waxes, phosphatides, cerebrosides, and related or derived compounds that with proteins and carbohydrates constitute the principal structural components of living cells" was used in specifying the following testing equipment.

	Equipment list price	*Installation, including overhead*	*Total*
Soxhlet extraction apparatus supplied with condenser, extraction tube, and flask (per case of 2)	$55		$55
Multiple unit hotplate	120		120
Extraction thimbles (per box of 25)	10		10

Numerous biological and chemical water sample analyses are defined in the Betz handbook (*17*). Additional water testing procedures are suggested with the necessary laboratory equipment in the 1966 Book of ASTM Standards (*18*). Most of these tests are of a wet chemical nature and include such analyses as dissolved oxygen, carbon dioxide, sulfates, chlorides, and acidity or basicity. The equipment required to perform them is generally of a laboratory glassware and hardware nature incorporating such apparatus as burettes, graduated cylinders, flasks, pipettes, pH paper, bottles, and bunsen burners. These items as well as necessary chemical reagents are priced and included under auxiliary laboratory equipment and supplies.

For the specific test for biochemical oxygen demand (BOD), reference was made to ASTM Standard: D 2329–65T (*19*). The apparatus required is as follows:

	Equipment list price	*Installation, including overhead*	*Total*
Incubation bottles with 300-milliliter capacity and ground-glass stoppers (per case of 24)	$55		$55
BOD bacteriological incubator, thermostatically controlled at 20±1° C with forced air circulator and externally mounted temperature indicators and controls	525	$50	575

The chemical analysis of flue gas samples taken periodically from incinerator stacks can be accomplished with speed and accuracy using a combination of chromatographic and spectrophotometric equipment. Considerable versatility is inherent with the chromatograph providing quantitative measurements and a spectrophotometer utilizing the infrared spectrum to furnish qualitative analysis. In this manner the inorganic and organic components of a flue gas sample can be determined whether they are present in large concentrations or just trace amounts. Among the compounds it might be desirable to test for are the inorganics; NH_3, SO_2, SO_3, CO_2, CO, NO_2, HCl and HF and the organics: acetic acid, formic acid, oleic acid, acetaldehyde, formaldehyde, phosgene, toluene diisocyanate, acetylene, and ethylene.

It should be mentioned that the above equipment could also be utilized for water pollutant analysis through direct injection and for some solids component analysis provided the samples are first dissolved in an applicable solvent.

The equipment suggested for the chemical analysis of flue gas and other liquid and vapor samples is as follows:

	Equipment list price	*Installation, including overhead*	*Total*
Dual-column gas chromatograph with flame ionization and hot wire detectors, gas flow controls, automatic programing controls, and chart readout recorders	$5,000	$200	$5,200
Infrared spectrophotometer with self-contained source, photometering optics, evacuated thermocouple detector, and chart readout recorder	7,000	200	7,200

To test for dangerous gases in the refuse storage pit the following equipment is suggested:

Vapotester (portable methane gas tester)	$410		$410

The auxiliary laboratory equipment and supplies suggested to more fully equip the standard chemical laboratory are tabulated in table 44.

The approximate cost of purchasing the equipment described for the group III section of this report is estimated at $73,955.

Approximately 1,100 square feet of floor space would be required for the installation of this equipment including working space and darkroom facilities.

TABLE 44
AUXILIARY LABORATORY EQUIPMENT

	Equipment list price	Installation, including overhead	Total
Extraction apparatus, ASTM-Underwriter's model, electric, 6 unit complete outfit with six 400-milliliter flasks, 6 siphon tubes, and neoprene tubing	$420	....	$420
Combination hotplate and magnetic stirrer	95	....	95
Titration lamp	30	....	30
Hygrometer, motor ventilated	80	....	80
Motor-driven rotary pump	80	....	80
Precision wet-test gas meter	375	....	375
Constant voltage transformer	35	....	35
Voltmeter	95	....	95
Ammeter	30	....	30
Galvanometer	75	....	75
Potentiometer (portable, thermocouple type)	300	....	300
Assorted laboratory hardware, tools, glassware, and implements such as various containers, stoppers, rubber tubing, Bunsen burners, thermometers, spatules, etc	2,000	....	2,000
Chemicals in solid, reagent, and gaseous form required for sample analysis testing as well as those used in ordinary laboratory procedures such as glassware cleaning	2,000	....	2,000

It is estimated that the addition of this space to the incinerator plant, complete with laboratory furniture, sinks, storage cabinets, electrical lighting and power outlets, plumbing fixtures, piping, and air conditioning, would cost $50,000.

GROUP IV

Monitoring Equipment for Test and Development Studies

This section covers the additional monitoring equipment recommended for continuous indication and recording of the operating conditions of a single incinerator furnace unit. The present lack of operating data seriously hinders the development of adequate incineration facilities. It is intended that the following equipment would be used to evaluate all of the variables of incinerator operation so that improvements could be recommended in incinerator design and operating practices.

The instruments tabulated for this section would be installed on a panel in a monitoring room where facilities would permit analysis of the recorded data. Control of the operation of the incinerator unit would remain at the panel provided for the group I instruments.

The primary variables to be recorded are the conditions of combustion air, furnace, flue gas, and process water.

The analyses of data from these records combined with analyses of refuse and residue will permit a determination of the effect of changes in operating conditions on overall incinerator performance.

Tables 45 and 46 show recommended equipment for recording of the above variables.

TABLE 45
MONITORING EQUIPMENT

Measurements	Equipment list price	Installation, including overhead	Total
Combustion air:			
Underfire air and overfire air flow recorders with special duct work arrangements for flow measurements	$9,200	$10,000	$19,200
Temperature recorder (12 positions) for underfire, wall cooling, and overfire air	1,660	1,600	3,260
Pressure recorders for draft and pressures in air zones, also including furnace, dust control equipment, and stack conditions	9,800	2,400	12,200
Forced draft fan motor current recorder	1,975	500	1,740
Furnace:			
Refuse feed rate recorder	1,340	760	2,100
Temperature recorder 24 point with chromel-alumel thermocouples for refractory temperatures to 2,000° F	2,675	2,400	5,075
Temperature recorder 24 point with platinum-rhodium thermocouple for refractory and face temperatures to 2,700° F	3,275	2,400	5,675
Temperature recorder 6 point with radiamatic elements in silaramic tubes for gas temperature measurements	3,275	1,800	5,075

Table 46
MONITORING EQUIPMENT

Measurements	Equipment list price	Installation, including overhead	Total
Flue gas:			
Flue gas flow rate recorder	$1,090	$2,000	$3,090
Carbon dioxide analyzer and recorder	2,200	1,800	4,000
Oxygen analyzer and recorder	3,000	2,000	5,000
Water vapor concentration recorder with infrared sampling and conditioning equipment	3,500	2,700	6,200
Stack emission particulate loading recorder including continuous sampling system	10,000	5,000	15,000
Temperature recorder, 24-point, 1-1 point with chromel-alumel thermocouples	2,765	2,400	5,075
Process water:			
Water flow rate recorder	2,100	1,500	3,600
pH analyzer and recorder 2 points	2,875	1,500	4,375
Temperature recorder 6 point	1,655	1,000	2,655
Turbidity recorder with flow chamber, light source and transmitter	1,800	1,200	3,000

This equipment in conjunction with the recording equipment of group I would provide for monitoring of the variables of operation of a single incinerator furnace unit.

The approximate purchased and installed cost for the group IV equipment of this report is $106,320.

Approximately 800 square feet of floor space would be required for the installation of the panels housing this recording equipment, including space for desks, reference tables, and storage cabinets for charts and supplies. It is estimated that the addition of this space to the incinerator plant, complete with office furniture, electric lighting, utility outlets, and air conditioning, would cost $25,000.

The operation and maintenance of this laboratory equipment will require specially trained personnel. The number of people employed will vary with the test schedules. It is assumed that a large percentage of the test work conducted with this equipment would be handled under research grants to colleges and universities.

References

(*1*) American Society for Testing Materials. Designation: D 271–64; standard methods of laboratory sampling and analysis of coal and coke. Revised 1964.

(*2*) American Society for Testing Materials. Designation: D 2013–65 T; method of preparing coal samples for analysis (tentative).

(*3*) Fisher Scientific Co. *Modern laboratory appliances catalog.* Pittsburgh, Fisher Scientific Co., 1963.

(*4*) E. H. Sargent and Co. *Scientific laboratory instruments, apparatus, supplies and chemicals catalog.* Chicago, E. H. Sargent and Co., 1964.

(*5*) Arthur H. Thomas Co. *Scientific apparatus and reagents catalog.* Philadelphia, Arthur H. Thomas Co., 1965.

(*6*) American Society for Testing Materials. Designation: D 1857–64 T; test for fusibility of coal ash (tentative).

(*7*) Jacobs, M. B., M. M. Braverman, S. Hochheiser, and I. Ettinger. Sampling and analysis of incinerator flue gases. Presented at the Air Pollution Control Association 51st Annual Meeting, Philadelphia, May 25–29, 1958. p. 7-1, 7-11.

(*8*) Rehm, F. R. Test methods for determining emission characteristics of incinerators; informative report No. 2. *Journal of the Air Pollution Control Association*, 15(3): 127–135, Mar. 1965.

(*9*) American Society Mechanical Engineers. Test Codes PTC 21–1941; dust separating apparatus.

(*10*) American Society Mechanical Engineers. Test Codes PTC 27–1957; determining dust concentration in a gas stream.

(*11*) Western Precipitation Corporation. *Methods for the determination of velocity, volume, dust and mist content of gases.* 4th ed. Los Angeles, Western Precipitation Corp., 1951.

(*12*) American Society Mechanical Engineers. Test Codes PTC 28–1965; determining the properties of fine particulate matter.

(*13*) American Society for Testing Materials. Designation: E 11–61; standard specifications sieves for testing purposes.

(*14*) Etzel, J. E., and J. M. Bell. Methods of sampling and analyzing refuse. *APWA Reporter*, 29(11): 2–4, 18–21, Nov. 1962.

(*15*) Regis, A. J. X-ray spectrographic analysis of incinerator slags. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 195–198.

(*16*) Environmental Engineering Department, Drexel Institute of Technology. Incinerator ash residue testing procedures for the analysis of moisture content, volatile matter, ash content, gross calorific value, sulfur, nitrogen, lipids, carbon, hydrogen, phosphorus (P_2O_5), and potassium (K_2O).

(*17*) Betz Laboratories, Inc. *Betz handbook of industrial water conditioning.* 6th ed. Philadelphia, Betz Laboratories, Inc., 1962. 425 pp.

(*18*) American Society for Testing Materials. Industrial water, atmospheric analysis. Part 23. *In* Standards. Philadelphia, American Society for Testing Materials, 1966.

(*19*) American Society for Testing Materials. Designation: D 2329–65 T; tentative method of test for biochemical oxygen demand of industrial water and industrial waste water (tentative). 1965.

BIBLIOGRAPHY

Public Health Service. *Selected methods for the measurement of air pollutants.* Washington, U.S. Department of Health, Education, and Welfare, 1965.

Manufacturing Chemists' Association, Inc. *Water pollution abatement manual; organization and method for investigating wastes in relation to water pollution.* Manual W–1. Washington, Manufacturing Chemists' Association, Inc., 1954, 7 p.

Manufacturing Chemists' Association, Inc. *Water pollution abatement manual; insoluble and undissolved substances.* Manual W–2. Washington, Manufacturing Chemists' Association, Inc., 1949. 10 p.

Manufacturing Chemists' Association, Inc. *Water pollution abatement manual; oils and tars.* Washington, Manufacturing Chemists' Association, Inc., 1955.

Manufacturing Chemists' Association, Inc. *Water pollution abatement manual; neutralization of acidic and alkaline plant effluents.* Manual W–3. Washington, Manufacturing Chemists' Association, Inc., 1960. 13 p.

Eckenfelder, W. W. *Industrial water pollution control.* New York, McGraw-Hill Publishers, 1966. 275 pp.

Stern, A. C. *Air pollution.* 2v. New York, Academic Press, 1962.

American Society for Testing Materials. *Manual on industrial water.* Philadelphia, American Society for Testing Materials, 1953. 336 p.

Low, M. J. D. Subtler infrared spectroscopy. *International Science and Technology,* 62(2): 52–58, Feb. 1967.

Steyermark, A. S. *Quantitative organic microanalysis.* Philadelphia, Blakiston Company Publishers, 1951. 389 p.

Kaiser, E. R. Chemical analysis of refuse components. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 84–88.

Cerniglia, V. J. Closed-circuit television and its application in municipal incineration. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 187–190.

Herbert, D. B. The nature of incinerator slags. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 191–194.

Woodruff, P. H., and A. W. Wene. General overall approach to industrial incineration. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers New York, May 1–4, 1966. p. 219–225.

Goder, R., and A. Marshalla. Incinerator testing programs, 1966. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 231–234.

Zinn, R. E. Progress in municipal incineration through process engineering. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 259–266.

size reduction

OF OVERSIZE BURNABLE WASTE

Abstract

Disposal of oversize burnable waste in the District of Columbia is presently conducted by direct burial or burning of these large objects in landfill operations. The incineration of these objects directly in the furnaces with normal municipal refuse does not produce acceptable burnout. The investigation of methods for size reduction of these objects to pieces that will burn compatibly with normal municipal refuse is described. An alternate method of disposal by burning dense objects in specially designed incinerators is also described. The installation of a shredder for size reduction is recommended.

Introduction

The Department of Sanitary Engineering in Washington, D.C., must provide a means to dispose of oversize burnable waste collected from the residents and industry which cannot be burned satisfactorily with normal household refuse in municipal incinerators.

Disposal of this material can be accomplished by open dump burning, by direct burial in landfill operations, by size reduction to permit burning in incinerator furnaces with normal household refuse, or by burning in bulk form in specially designed incinerator furnaces.

Good practice in dump operations or landfill rules against disposal by open burning or direct burial in landfill. We have been requested to study methods of size reduction of this oversize burnable waste to permit incineration with normal household refuse in the proposed Incinerator No. 5.

Our studies indicate that disposal of some objects, such as large tree stumps, by size reduction for incineration is not always possible. This report therefore includes discussions of both size reduction and special burning equipment.

Summary and Recommendations

The disposal of oversize burnable waste in landfill operations or by open dump burning is not acceptable in today's society because of rodent problems, land settlement, and air pollution resulting from these activities.

This material can be burned in specially designed incinerators or it can be shredded and mixed with municipal refuse for burning in a conventional refuse incinerator. The shredding of most objects presents no unusual problems, however, certain dense objects such as large tree stumps require special handling as present-day shredders cannot satisfactorily handle them.

Two methods of disposing of large tree stumps or other dense objects are proposed. One method is to burn them in a special incinerator. The second method uses a special machine for splitting the stumps in the ground for removal in pieces which can be hand-loaded into a truck. Both of these disposal methods are currently in use.

We recommend that there be installed at the proposed No. 5 Incinerator plant a large shredder of the hammermill type with grate bars selected to discharge a product approximately 1″ x 8″ x 6″ in maximum dimensions. This unit is estimated to cost $667,000 to install and approximately $125,000 per year to own and operate. The ability of this unit to also handle bulky metal objects will elimate the need for installation of a metal press at this site. Separation of ferrous metal from the output of the shredder, therefore, is included in this estimate as passage of excess metal through the furnace is not recommended.

Availability of mobile stump splitters in the Washington, D.C., area should permit the enforcement of regulations which would require that all tree stumps be delivered to the disposal plants in pieces suitable for charging into this shredder.

The use of a special bulky refuse incinerator does not appear to be justified where the shredder application can be employed. For comparison, the installed cost of a bulky refuse incinerator is estimated at $532,000, with annual operating costs of $104,000, including an independent air pollution control system. The use of the main incinerator furnace flues and fly ash control equipment for the products of combustion from a bulky refuse burner is not recommended where strict air pollution requirements exist.

TYPES OF OVERSIZE BURNABLE WASTE

The refuse collection units of the Division of Sanitation collect substantial quantites of oversize burnable waste which cannot be acceptably mixed with household refuse. These collections include such items as: rubber tires—passenger and off-the-road types; Christmas trees, brush, branches; overstuffed and wood furniture; demolition lumber, logs, poles; boxes, crates, pallets and skids; bundles of paper and cardboard; mattresses.

In addition, the District employees remove and must dispose of approximately 6,000 tree stumps annually, having an average trunk diameter of 32 to 34 inches.

The above listing does not include bulky metal objects such as refrigerators, washing machines, and stoves. The handling of bulky metal objects for disposal is discussed in the following section entitled *Size Reduction of Bulky Metal Objects by Compression Presses*. These objects can also be shredded in equipment suitable for size reduction of oversize burnable waste as discussed in this report.

DISPOSAL METHODS

Disposal of oversize burnable waste by open burning creates a public nuisance and seriously adds to air pollution problems in the area of burning. Direct burial of these objects in landfill operations consumes landfill space at a rapid rate. It also tends to create voids in the landfill which can harbor rodents and vermin. The ultimate decomposition or decay of the burnable material allows landfill settlement to occur over extended periods of time, thereby reducing the value of the landfill for future development, even for use as park areas.

Two alternatives for disposal of oversize burnable waste are considered in this report. The first method consists of size reduction by shredding in specially designed size reduction equipment to permit incineration in furnaces designed for the burning of normal municipal refuse. The second disposal method consists of burning the bulky objects in a specially designed incinerator that will permit the objects to remain in the furnace atmosphere until complete burnout is obtained. This furnace must necessarily be equipped with adequate air pollution control equipment.

Equipment required for destruction of oversize burnable waste by shredding followed by normal incineration; or, by direct burning without size reduction in specially designed incinerators; has been in operation in this country for several years. Both methods have operating limitations which are discussed in further detail in the following sections of this report.

EQUIPMENT FOR SHREDDNG

The preparation of oversize burnable waste for destruction in a conventional refuse incinerator requires a reduction in size to pieces that will be completely consumed in the incinerator furnace.

Several types of shredding equipment are available for the size reduction of those objects listed in the section of this report, "Types of Oversize Burnable Waste." None of the units investigated, however, could process all of those items listed to an acceptable end product without certain operating limitations.

Three types of mills were investigated for this shredding application. These are as follows: Impact mills; hammermills with grates; and knife hogs. The principal features and performance of these mills are described as follows.

Impact Mills

Impact mills reduce the size of bulky objects by the action of projections on a rotating mandrel (or cylinder) tearing away pieces of the charged object (fig. 4). A further reduction in the size of these pieces is obtained by multiple impact between anvils in the outer case of the machine and the projections on the mandrel. The anvils are normally spring-loaded to permit automatic release so that large dense objects will not wedge in the machine and jam its action.

Impact mills do not have any grates to control the size of the discharged material. As a result most of the material entering the machine is discharged after traveling approximately one-half the distance around the inside perimeter of the unit. This results in a wide variation in dimensional characteristics of the discharged material. Some objects such as rubber tires, mattresses, and cushions may pass through the machine with only a partial reduction in size.

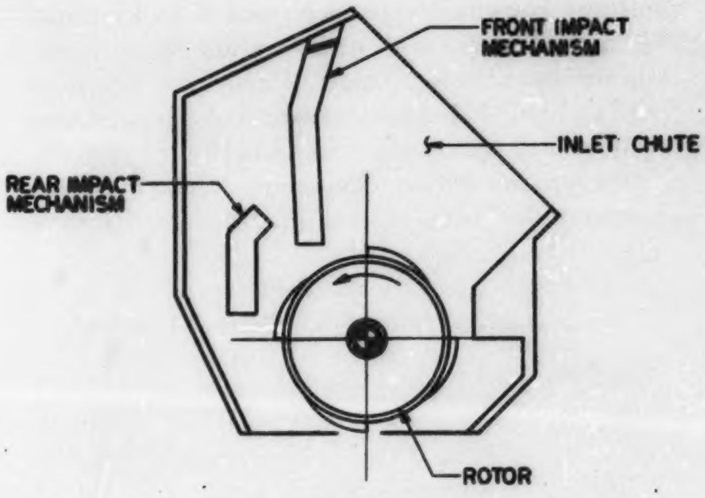


Fig. 4. *Schematic arrangement of an impact mill.*

Hammermills with Grates

Hammermills with grates reduce the size of bulky objects by the action of floating "hammers" which are rotated within the case at relatively high velocity (fig. 5). These hammers tear away pieces of the charged object and constantly strike against these pieces as they rotate within the machinery case until the pieces are sufficiently reduced in size to pass through the grate openings. This type of machine has a limitation on the size reduction that can be accomplished in a single pass at maximum rated capacity. Suitable size reduction can be obtained at reduced capacities or by operating machines in series to effect a two-stage size reduction.

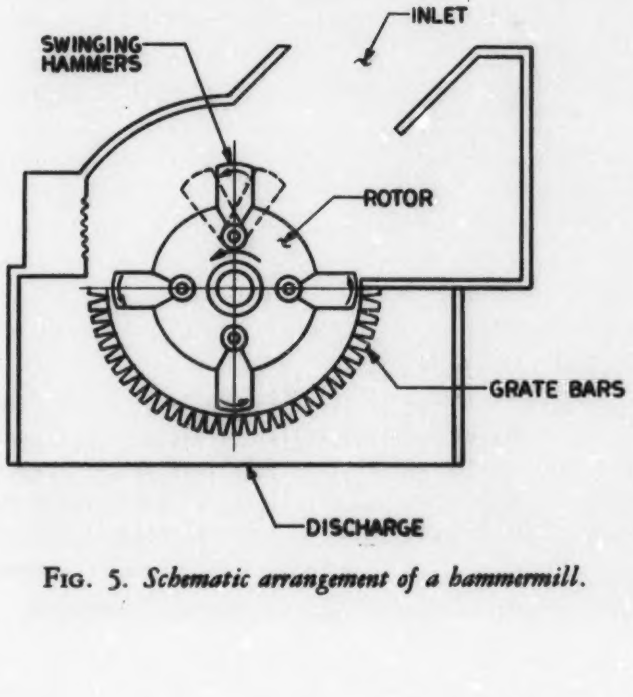


Fig. 5. *Schematic arrangement of a hammermill.*

Knife Hog

The knife hog has a rotating mandrel with sharp edged blades which shave away pieces of the charged object and discharge them at the far side of the machine (fig. 6). Some units are provided with internal blades fixed in the perimeter of the machine case and meshing with blades on the rotating mandrel to provide a punching or shearing action for further size reduction of the shaved pieces. This type of unit cannot accept any objects containing metal without possibility of damage to the knives or blades.

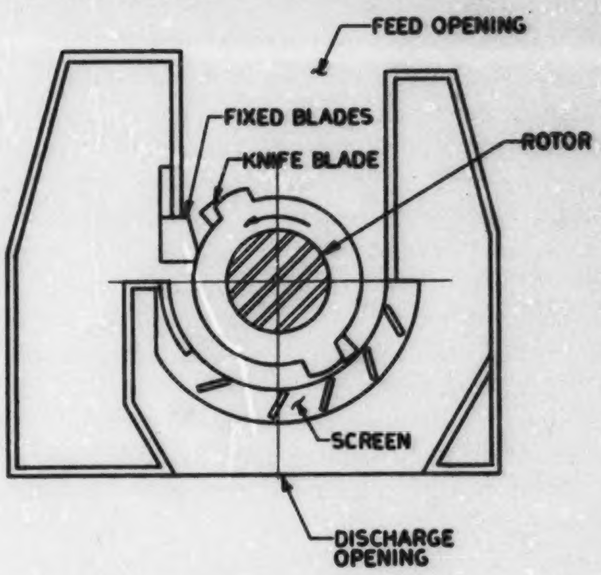


Fig. 6. *Schematic arrangement of a knife hog.*

Machine Limitations

A review of the above machines indicates the following limitations must be considered: *Rubber tires* can be reduced in a hammermill with grates if the size and horsepower of the machine are adequate. Removal of the wire bead before shredding is common commercial practice. Tires may pass through an impact mill with only limited size reduction. The wire bead of the tires will damage knife hogs. *Tree stumps* of larger sizes are beyond the capacity of present day shredding equipment. Smaller sizes or pieces of stumps can be splintered in a hammermill or impact mill. *Domolition lumber* can be processed in a hammermill or impact mill. The maximum length of timber is normally limited to 6 feet for moderately powered machines. The initial size reduction may produce pieces up to 4″ in thickness depending upon the specific design of the machine. In these cases a second stage of size reduction will be required to limit the maximum size to the dimensions specified above.

Mattresses and springs are handled best by the hammermill. Size reduction of these objects in an impact mill is not consistent. *Bulky metal objects* can be processed in the impact or hammermills for size reduction and shredding. Equipment selected for this type of operation is currently being used to replace hydraulic presses where metal recovery is a consideration.

EFFECTS OF SHREDDED MATERIAL ON FURNACE OPERATIONS

Combustible refuse to be burned in a conventional incinerator furnace must be reduced in size to pieces that can be fully incinerated within the time the material is allowed to remain in the furnace.

The normal retention time in a modern continuous feed incinerator furnace ranges from 30 to 45 minutes depending upon design conditions. It is our opinion that combustible material must be reduced to less than 1 inch in thickness to ensure acceptable burnout when fired with conventional refuse. The thickness of the combustible material is considered critical. Length and width dimensions should not exceed 8″ x 2″, although these are not critical. This size specification should assure the optimum burnout in the furnace of the more dense components. Unfortunately, reduction to this maximum size will produce an abundance of smaller pieces. Precautions must be taken to distribute the shredder discharge product throughout the other refuse being burned to prevent charging the furnace with a homogeneous mass of particles that will obstruct airflow through the burning materials.

Metallic objects discharged from a shredder may be mixed with the combustible refuse to be burned on an incinerator stoker. In some cases, these pieces of metal may cause trouble on a continuous feed stoker. The smaller pieces of metal and wire may wedge into or clog air openings in the grate. The sharp edges of some larger pieces can be forced by the grate action against the refractory surfaces with possible resultant damage to the refractory.

The destruction of large quantities of bulky metal objects in a shredder for feed to a continuous feed stoker furnace should not be considered at this time. Where a shredder is installed for destruction of a mixture of oversize burnable waste and bulky metal objects, a magnetic separator should be installed to remove ferrous metal from the product prior to its entry into the furnace units.

The impact mill and hammermill are capable of shredding household appliance types of bulky metal objects. Continuous feed of large quantities of metal from the destruction of these objects however, may result in high stoker and furnace maintenance costs for the reasons stated previously. Additional research at the operating level is required to evaluate fully the aspect of incineration of shredded metal objects with refuse.

INCINERATORS FOR BURNING BULKY OBJECTS

The investigation into suitable methods for disposal of the large tree stumps covered several alternate procedures including the possibility of splitting the stumps for ultimate size reduction in a shredder as described later in this report. An alternative to splitting the stumps is a reduction by burning in a special incinerator designed for the destruction of this type of material. Several bulky object incinerators are presently in service in this country and some research studies are being conducted into their operation (*1*).

These units operate on a batch feed basis. They are constructed with refractory walls and roof arches which help to hold temperatures in the furnace at the high levels necessary to maintain ignition for burning through heavy timbers, logs, and tree stumps. Less dense objects, such as furniture, mattresses, and automobile tires are used as tinder for the ignition of these units.

It is anticipated that large tree stumps would be charged into the furnace about every 2 hours during the day shift and then be allowed to burn down overnight. Ash would be removed from the furnace once a day before the initial charge. Metallic residue from from the bulky waste would be removed with the ash. This metal is normally in an annealed condition and should present no problems for disposal in a landfill.

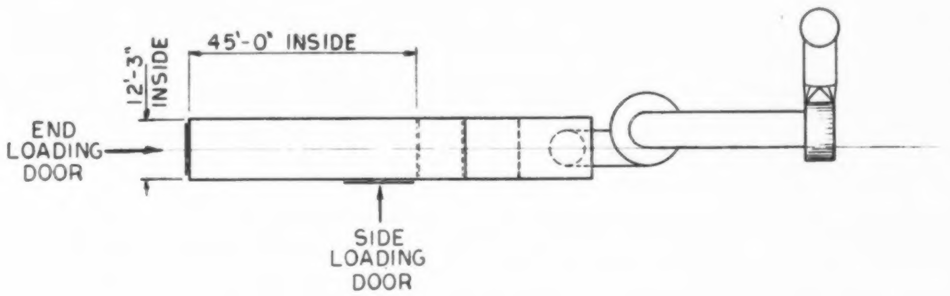
Refuse is charged into furnaces of this type with a front-end loader provided with a removable extended pusher blade. The same unit, with the blade removed, is used for ash removal. A crew of three to four men is normally provided during the brief periods of time required for charging and ash removal operations. Periodic checking during burn-down cycles will require the parttime services of one man.

Air pollution from a bulky refuse incinerator could become a problem if no control equipment is provided. As reported in the first section of this report, the products of combustion of automobile tires and from some of the organic constituents of the tree stumps may require control. The installation of wet scrubber type of air pollution control equipment to remove both particulate matter and soluble gaseous products of combustion should be provided for this type of incinerator. A vapor plume will exist under certain operating conditions.

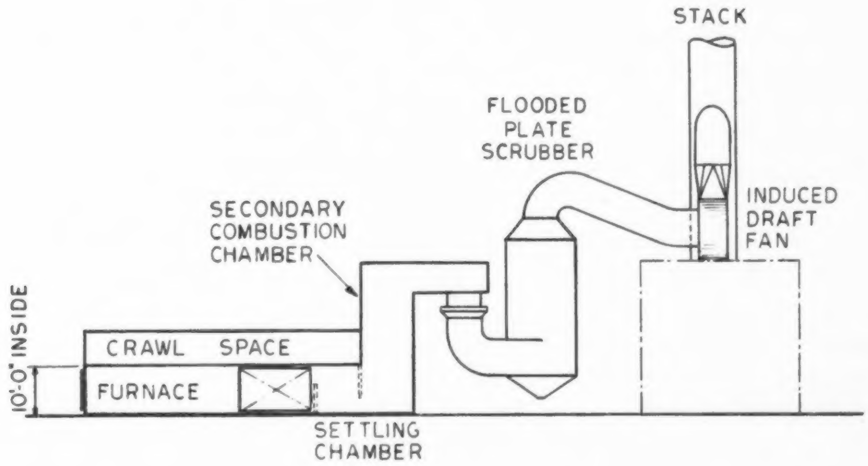
The design of a bulky refuse burner would be generally as shown in figure 7. Adequate provision must be made for burnout of the volatile matter and particulates before the hot gas stream is quenched prior to its entry into the associated air pollution control equipment. A study would be required to determine the need for auxiliary firing into the secondary combustion chamber as an aid to ensure complete burnout. The need for this auxiliary firing will depend upon the type of material burned and the arrangement of the flues. Certain types of bulky refuse may also require auxiliary firing in the main combustion chamber.

EQUIPMENT FOR SPLITTING TREE STUMPS

The inability of the size reduction equipment investigated to handle stumps from large size trees required an investigation into possible methods of splitting these stumps into pieces that would be acceptable to shredding equipment. This investigation covered procedures including blasting, sawing, and splitting with large hydraulically operated wedge presses. None of these procedures was considered acceptable because of maintenance, noise and/or stump handling difficulties.


45'-0" INSIDE
12'-3" INSIDE
END LOADING DOOR
SIDE LOADING DOOR

PLAN


STACK
FLOODED PLATE SCRUBBER
INDUCED DRAFT FAN
SECONDARY COMBUSTION CHAMBER
10'-0" INSIDE
CRAWL SPACE
FURNACE
SETTLING CHAMBER

ELEVATION

FIG. 7. *Schematic arrangement of a bulky refuse burner with wet scrubber for flue gas.*

One item of commercially available equipment (2) was investigated which is known to remove stumps from the ground in pieces small enough to be processed in a shredder for final burning in an incinerator. This unit is designed for installation on a crawler shovel or large rubber-tired crane. It operates by pulling a large shaped blade through the ground and stump, cutting the stump and roots into pieces which can be hand loaded into a truck.

The designer of this equipment has proposed that he build a similar unit to split stumps that have been removed intact from the ground. This unit would operate by driving a blade down into the stump with a vertical blow. Splitting of the stumps after removal from the ground at a central location would result in a local noise problem as impact of the blade into the stump would be a major factor in the success of this operation. Maintenance of the yard in which this activity is conducted would also be a consideration.

These units have the mobility to move from stump to stump and therefore reduce stump handling problems that would be encountered with other methods considered. The availability of such equipment makes it possible for a municipality to require that stumps be delivered to the disposal sites in pieces small enough for further destruction by a shredder.

Capital and Operating Costs

Shredder Installation

A shredder installation for size reduction of oversize burnable waste should consist of shredding equipment of adequate capacity to handle the most difficult object anticipated plus necessary feed and discharge conveyors. The shredder should have a feed opening approximately 80 inches long by 48 inches high.

The installation should be capable of reducing the size of both the combustible components making up the majority of the feed and the incidental metal attachments, fasteners, and inclusions. Motor requirements for the shredder will range from 300 to 1,000 hp., depending upon the specific unit selected. In specifying the unit it is important that the manufacturer be advised of the range of material to be processed so that the proper grate size and motor horsepower can be provided. Shredding of bulky metal objects in addition to the oversize burnable waste will affect the selection of the equipment.

The associated materials handling equipment should include a feeder to discharge into the loading hopper of the shredder. Safety screens are necessary to prevent injury to workers in the area from flying objects ejected from the charge hopper by action of the hammers in the shredder.

The discharge from the shredder should be conveyed to a storage bin at the tipping floor level. Magnetic separation is desirable in this conveyor assembly to discharge ferrous material into a separate bin. The combustible material can be removed from the storage bin and loaded into the refuse bins by a front-end loader. This is considered the most practical method of distributing the shredded material throughout the balance of the refuse. The alternate use of the plant cranes, belt conveyors, and pneumatic conveyors for distribution of the shredded material was investigated but the front-end loader appears to provide the best flexibility of operation at minimum operating and maintenance costs.

The ferrous material can be loaded into trucks for sale to metal dealers or it can be trucked to the disposal site and buried with the ash residue from the furnaces.

We estimate the installed cost of this equipment in a location adjacent to the tipping floor and refuse pit would be approximately $667,000. This estimate includes the foundations for the shredder and associated equipment.

The estimate also includes special dust control equipment, a motor ventilation system, and provisions for sound attenuation of the noise generated by the shredder. It does not include the architectural housing over the equipment which is considered part of the main incinerator plant.

The operation of the shredder would normally be scheduled for the day shift. It is anticipated that this activity would require the services of a machine operator and three laborers. Electric power and maintenance would add to the total annual operating costs.

The following is a summary of the estimated capital investment and annual costs for operation of a shredder designed to handle oversize burnable waste and bulky metal objects.

Bulky Refuse Incinerator

A bulky refuse incinerator for direct burning of oversize burnable objects including larger tree stumps would be constructed as shown in the schematic arrangement drawing figure 4. The furnace would be constructed with a refractory hearth and refractory

TABLE 47

SUMMARY OF ESTIMATED CAPITAL INVESTMENT AND ANNUAL COST

	Cost
Capital investment:	
Foundations and concrete work	$134,700
Purchased equipment costs including delivery	248,300
Installation costs including electrical	138,800
Front-end loader	25,000
Installed cost of physical equipment	546,800
Engineering and field supervision	39,200
Contingency	54,000
Escalation to December 1968	27,000
Total estimated project cost	667,000
Operating cost:	
Labor	30,000
Electric power	25,000
Maintenance	8,000
Total direct operating cost	63,000
Annual fixed charges, 15 years at 4½ percent	62,000
Total annual owning and operating cost	125,000

walls and roof arches from the charging doors to the wet scrubber. The furnace would be designed with mechanically operated full opening doors. It would be charged by means of a mobile front-end loader with pusher blade attachment to push the bulk material into the furnace. The unit would be complete with both forced and induced draft fans and a wet scrubber for air pollution control.

It is estimated that a unit of this type will burn approximately 16 pounds of waste wood products per hour per square foot of hearth area (3). The unit shown would average about 8,800 pounds per hour capability of bulky burnable material.

This unit could be installed in the service yard at the rear of the incinerator plant using the wet scrubber as included in the following estimate, or the scrubber could be eliminated and the hot gases directed into the exit flue from one of the incinerator furnaces. The use of the main incinerator furnace flues would require that the capacity of the furnace affected, be reduced by the equivalent of the material being burned in the bulky refuse incinerator. This would require one-half capacity operation of the incinerator furnace for units of the size being considered, a procedure that is not recommended, as reduced capacity operation is not readily obtainable without operating difficulties such as burn-back into charge hoppers of the refuse furnace.

A second alternative is to increase the size of the air pollution control equipment of the furnace affected to permit it to handle approximately 50 percent more gas volume. This arrangement will affect the efficiency of the air pollution control equipment which is to some extent proportional to the gas velocities through the equipment. It will also present some operating problems in the control of the induced draft equipment to maintain balanced operation between the two units.

A preliminary review of capital costs does not indicate any substantial savings would be obtained in passing the flue gas from the bulky refuse incinerator through oversized air pollution control equipment of one of the main incinerator furnaces.

The following is a summary of the estimated capital investment and annual costs for operation of a bulky refuse incinerator with independent air pollution control equipment. The estimate is based on the use of a stub steel stack for discharge of the products of combustion. The estimate includes subsurface foundations, architectural treatment of the furnace enclosure, necessary river water piping, a settling basin for fly ash removal, and the river water intake structure and pumps.

Capital Investment

General building, foundation and concrete work	$68,750
Purchased equipment delivered to site	152,100
Mechanical installation and refractory work	199,300
Electric light and power	16,250
Installed cost of physical equipment	436,400
Engineering and field supervision	30,600
Contingencies	43,600
Escalation to December 1968	21,800
Total estimated project cost	532,400

Operating labor required to charge the furnace and remove ashes would be assigned on a part time basis during the day shift with periodic inspection during the night shifts. It is estimated that total labor costs on the part time basis would be $31,600 per year including supervision, labor, and a machine operator. The total annual owning and operating costs would be as follows:

Operating Costs

Labor	$31,600
Electric power	12,900
Maintenance	10,000
Total direct operating costs	54,500
Annual fixed charges, 15 years at 4½ percent	49,500
Total annual owning and operating costs	104,000

REFERENCES

(*1*) KAISER, E. R. The incineration of bulky refuse. *In* Proceedings, 1966 National Incinerator Conference, American Society Mechanical Engineers, New York, May 1–4, 1966. p. 39–43.

(2) Private communication, Bles Stump Axe Co., Tyson's Corner, McLean, Va.

(3) Private communication, E. R. Kaiser, November 1966.

size reduction of bulky metal objects

BY COMPRESSION PRESSES

Abstract

This report discusses methods for municipal disposal of bulky metal objects. The use of compression presses to reduce the volume of these objects was investigated and found to be acceptable under certain conditions. Capital investment estimates and evaluation of operating costs for metal presses installed at two separate locations are reported. The amount of metal to be handled in the District of Columbia is not sufficient to achieve a good economy of operation. The alternate use of outside contractors or metal shredding as a potentially more economical solution is recommended.

Introduction

In the field of municipal refuse collection and disposal, a serious problem is presented by large bulky metal objects which are both incombustible and unsatisfactory for direct burial in sanitary landfills. These objects consist largely of discarded refrigerators, washing machines, stoves, water boilers, bed springs, oil drums, etc. Where there is lack of interest by local scrap dealers in the salvage of this material, it may be disposed of in landfills. Good landfill operation, however, rules against disposal by this method because the voids created can harbor rodents and vermin. Also, decomposition of the metal by rusting allows settlement of the reclaimed land to eventually occur and the volume of scarce landfill space taken up is excessive. Hence, reduction of the bulk becomes desirable.

This report discusses the investigation of compression presses to accomplish size reduction of bulky metal objects and presents recommendations regarding the installation of such equipment in Washington, D.C. Two installations of hydraulic press units were investigated, located, respectively, at the transfer station and the site of the proposed Incinerator No. 5. The smaller unit selected for the transfer station because of space limitations is capable of handling most household type appliances. The larger unit selected for installation at the incinerator plant would be capable of handling most bulky metal objects anticipated for discard in a large city, including automobiles where necessary.

Summary and Recommendations

The undesirable effects of burying bulky metal objects in landfill operations in the District of Columbia could be alleviated by the immediate installation of a hydraulic compression press at the refuse transfer station located at New Jersey Avenue and K Street SE. This installation would cost approximately $147,000. Operating expenses are estimated to be $11 per ton of metal processed. No economic savings would be obtained by this installation but an undesirable condition would be eliminated.

We recommend as a more satisfactory solution, the installation of a shredder at the site of the proposed No. 5 Incinerator to handle both bulky metal objects and oversize burnable waste. However, at least 3 years may elapse before this plant could be placed in operation. The installation of a bulky metal press for use during the intervening period is not economical. We recommend that consideration be given to an agreement with a local scrap yard owner to compress with his equipment the bulky metal objects currently being collected by the city. A temporary contract based on the city delivering the material to the scrap yard and hauling the bales to landfill could be advantageous.

The installation of a large press at the proposed incinerator plant for a capital investment of $255,000 is not recommended where suitable shredding equipment is installed to handle both oversize burnable waste and bulky metal objects.

SOURCE AND QUANTITY OF BULKY METAL OBJECTS

Residents of the District of Columbia discard bulky metal objects by placing them on the curbside in accordance with schedules issued by the Division of Sanitation. This refuse is collected by city trucks and currently is being trucked to an open dump. About 6,700 items were collected during the 1965–66 fiscal year, broken down as follows:

	Units
Refrigerators	2,300
Washing machines	1,700
Stoves	800
Water boilers	400
Bedsprings	1,100
Oil drums	300
Air conditioners	100

In addition, appliance dealers and private collectors hauled an estimated equal quantity to the open dump. Thus, it may be stated, that approximately 15,000 bulky metal objects must be disposed of annually. It should be noted that oversize burnable waste such as overstuffed furniture, mattresses, etc., are not included in the above figures. The disposition of oversize burnable waste is discussed in the preceding section, *Size Reduction of Oversize Burnable Waste*.

DISPOSAL METHODS

Satisfactory disposal of bulky metal objects either for scrap metal salvage or for burial in sanitary landfills requires a reduction in the volume of the material collected.

The advent of new technological processes in the manufacture of steel, most particularly the basic oxygen furnace, has reduced the demand for scrap iron and upgraded the quality of scrap steel suitable for use as raw charge. This has lowered the value of unprocessed scrap to the point where it is uneconomical in most cities for scrap dealers to resell the material as collected. Up to the present time, Washington, D.C., has been one of those cities where waste metal cannot be advantageously disposed of by the municipality through scrap dealers to the steel industry.

Volume reduction of bulky metal objects may be accomplished by two basic methods. The first consists of shredding the objects to reduce them to an accumulation of small pieces which will occuppy considerably less volume than in their original condition. The second method is to reduce the volume by compressing the bulky material in a large mechanical or hydraulic press. If the metal is to be sold to scrap metal dealers, the first method would be preferable because contaminants can be eliminated by magnetic separation. Scrap metal of higher percentage iron content and better melting characteristics is produced. Compression of bulky metal objects produces a bale of crushed metal approximately 1/20 of the size of the original objects. This bale contains impurities such as insulation, aluminum, copper, etc., which are not desirable in scrap sold for melting. Either method produces suitable material for burying in sanitary landfills.

Machinery is commercially available for processing scrap by either of these methods. This equipment is necessarily in the class of heavy machinery with moderate to large power demands. Shredders may also be used to reduce bulky combustible wastes into material suitable for charging directly to municipal incinerators. For this reason, discussion of this type of equipment is contained in the companion section, *Size Reduction of Oversize Burnable Waste*.

Although baling presses may be either of the mechanical or hydraulic type, the latter has a much wider application in this field because of the relative ease with which high compression pressures may be achieved. Professional scrap dealers have used hydraulic balers for many years although many are now switching to shredders.

COMPRESSION EQUIPMENT

The principal factor governing the selection of a hydraulic press is the maximum size of bulky metal objects to be handled. The charge opening has to be big enough to admit the object and the cavity has to be deep enough to permit the door of the press to be closed.

The largest object likely to be encountered by a municipal installation would be a supermarket frozen food display case having overall dimensions approximately 12′ x 5′ x 5′. If the sizes of bulky metal objects are limited to those of typical household appliances, a press with an opening 8′ x 4′ should be adequate.

It should be noted that most large balers are built to accommodate objects 30″ deep and that household type appliances rarely exceed this dimension. Commercial operators usually resort to crushing when an object is too large. This crushing is normally done by dropping the objects on each other.

A truck-mounted crane with hydraulic boom and orange peel grapple can be used to charge the baler. This equipment may also be used to remove ejected bales, unload incoming trucks, and load outgoing trucks.

In many instances it is advantageous to use the baler to compress loose miscellaneous scrap metal such as panels, sheet metal, and scrap. This material can be handled by a hydraulically operated charging pan which would permit the operator to prepare a new charge while the press is going through a compression cycle. The addition of this feature would depend on the required production rate for the facility and the type of material to be handled.

The design of machines varies slightly between manufacturers. They normally operate in a horizontal plane with a top charge opening and a hydraulically operated cover or door which can either slide across or swing down over the cavity. Two hydraulically operated platens within the press are then operated to produce the finished bale. The first normally moves the length of the press cavity to a position which determines the width of the finished bale. The second platen is then stroked at right angles to the first to produce a finished bale approximately square in cross section and equal in height to the depth of the charge cavity. The finished bale is usually ejected by further hydraulic action to a position alongside of the unit where it can be picked up by a crane. The pressure on the face of the final ram will range from 1,000 to 1,800 pounds per square inch depending on the design of the specific machine and its hydraulic system. Larger presses sometimes use two hydraulic cylinders per platen to obtain a better distribution of forces.

The finished bale density is normally 100 to 150 pounds per cubic foot, depending on the amount of voids in the scrap metal being compressed. The volume reduction will usually be 20 to 1 when the press is charged with the material similar to household appliances.

A baling press of this type, when operated by commercial scrap dealers, can generally handle 5 to 20 tons of metal per hour. However, the bulkier the material, the lower the rate, since the time consumed in charging constitutes a large percentage of the time cycle. Also the size reduction ratio of 20 to 1 only applies to the bulkier material.

It is feasible to install a scrap metal baler in the open but a housing for the hydraulic and electrical control systems is desirable. The press should be located adjacent to its control equipment.

A representative list of hydraulic baling equipment manufacturers has been included in appendix A.

PROPOSED EQUIPMENT INSTALLATIONS

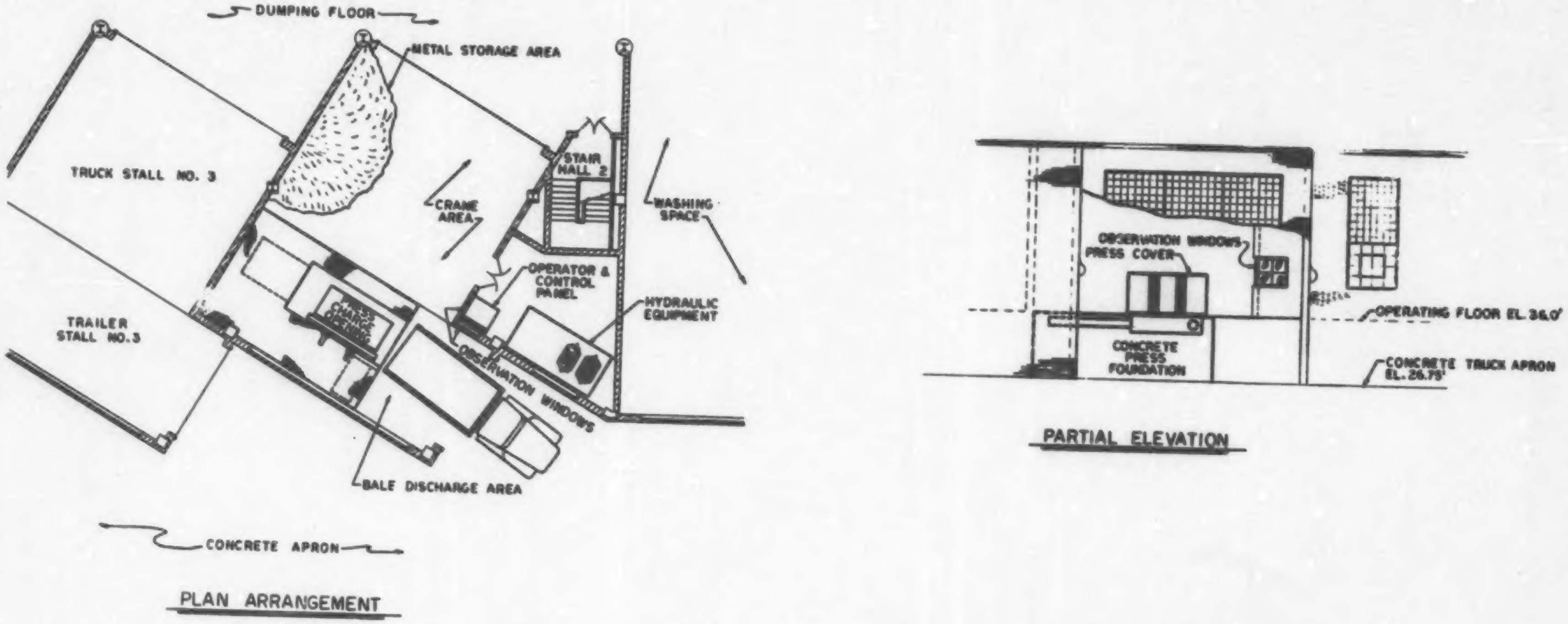
The installation in the District of Columbia of two hydraulic bale presses for compressing bulky metal objects has been investigated. A program arranged to integrate with other solid waste disposal facilities would be to install one at the existing transfer station located on New Jersey Avenue and K Street SE., and the other at the site of proposed Incinerator No. 5, east of the Anacostia River.

Although one of the larger size presses could handle the largest objects anticipated, it cannot be accommodated spacewise at the existing transfer station. On the other hand, there will be no supporting facilities available at the site of Incinerator No. 5 for 3 years. Therefore, a smaller press installed immediately at the transfer station to be followed later by a larger press at the new incinerator could provide an immediate solution to the current disposal problem and additional flexibility after 3 years.

A proposed arrangement for a press at the transfer station is shown in figure 8. A press with a charge opening approximately 10 feet long by 4 feet 6 inches wide by 30 inches deep can be installed in trailer stall no. 4, with the hydraulic system and control console located in the adjacent storage room. All normally encountered household appliances could be accommodated by this press. Bulky material would be stored on the operating (dumping) floor and charged to the press by a mobile crane operating on the dumping floor in truck stall no. 4. Necessary locker and toilet facilities for the operating personnel are available at the transfer station.

A larger unit, having a charge opening with dimensions of approximately 14 feet by 6 feet by 44 inches deep could be installed at the new incinerator plantsite. A press of this size can handle bulky metal objects ranging in size up to automobiles with engines and transmissions removed. It may be installed as part of the main building or at the corner of the proposed incinerator plantsite with the hydraulic system and controls housed in an independent structure as shown in figure 9. Bulky metal waste would be stored in an area adjacent to the structure, with landscaping as necessary to screen the working area from public view. Materials handling would be accomplished by a mobile truck-mounted crane operating in the adjacent yard. It is anticipated that the operating personnel would use the locker and toilet facilities of the incinerator plant.

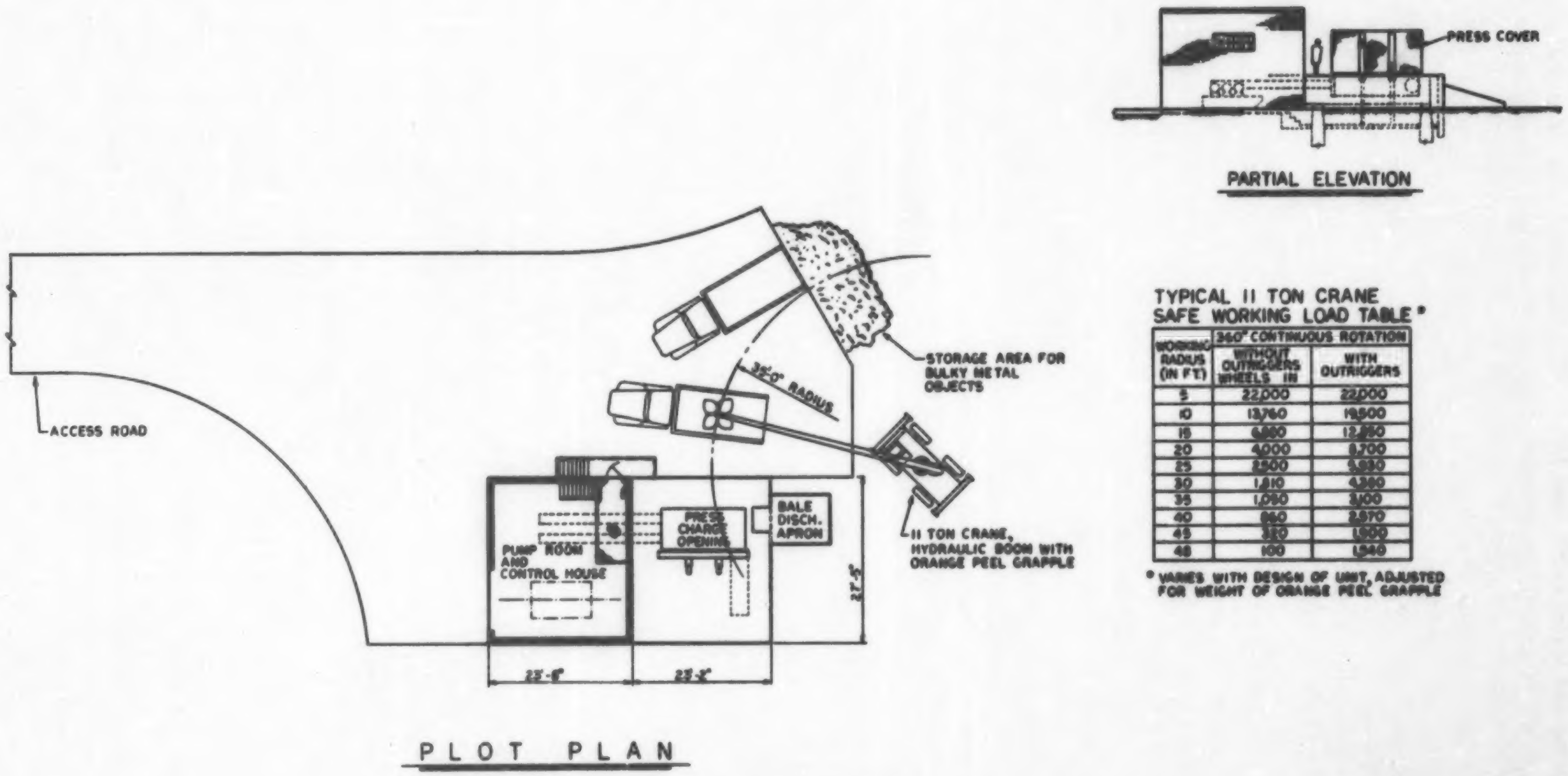
An advantage of integrating the press installation with the incinerator proper would be the ability to


DUMPING FLOOR
METAL STORAGE AREA
TRUCK STALL NO. 3
CRANE AREA
STAIR HALL 2
WASHING SPACE
OPERATOR & CONTROL PANEL
HYDRAULIC EQUIPMENT
PRESS CHARGE OPENING
TRAILER STALL NO. 3
OBSERVATION WINDOWS
BALE DISCHARGE AREA
CONCRETE APRON
OBSERVATION WINDOWS
PRESS COVER
CONCRETE PRESS FOUNDATION
OPERATING FLOOR EL. 36.0'
CONCRETE TRUCK APRON EL. 26.75'

PLAN ARRANGEMENT

PARTIAL ELEVATION

Fig. 8. *Proposed arrangement for installation of a bulky metal press at transfer station.*


PRESS COVER
PARTIAL ELEVATION
STORAGE AREA FOR BULKY METAL OBJECTS
35'-0" RADIUS
ACCESS ROAD
11 TON CRANE, HYDRAULIC BOOM WITH ORANGE PEEL GRAPPLE
BALE DISCH. APRON
PRESS CHARGE OPENING
PUMP ROOM AND CONTROL HOUSE
5'-2"
23'-6"
23'-2"
PLOT PLAN

TYPICAL 11 TON CRANE
SAFE WORKING LOAD TABLE*

WORKING RADIUS (IN FT)	360° CONTINUOUS ROTATION	
	WITHOUT OUTRIGGERS WHEELS IN	WITH OUTRIGGERS
5	22,000	22,000
10	13,760	19,500
15	6,880	12,850
20	4,000	8,700
25	2,500	5,930
30	1,810	4,300
35	1,050	3,100
40	860	2,570
45	320	1,900
48	100	1,540

* VARIES WITH DESIGN OF UNIT, ADJUSTED FOR WEIGHT OF ORANGE PEEL GRAPPLE

Fig. 9. *A compression press arrangement.*

use the same truck routing and scales as are used for normal refuse handling. Even though the press would be located adjacent to the refuse pit, it would not be practical to use the bridge crane for charging the press, but it could be possible to transfer out of the pit bulky objects which might be inadvertently dumped there when mixed with normal refuse. The best operation would still require a separate mobile truck-mounted crane for normal charging and bale removal operations.

Four men would be required to handle the work at each press unit, namely: a crane operator, a hydraulic press operator, a truck driver, and a laborer. However, this would not be a full-time task. The equipment could be manned by workers with other work assignments in the transfer station or incinerator plant. The work would include loading the press, forming the bales, and handling and transporting the bales to the landfill. Maintenance could be handled by contract with a local shop or by maintenance personnel employed at the transfer station and/or incinerator plant.

ESTIMATED CAPITAL INVESTMENT COSTS

The estimated cost of installation of an intermediate size press in the transfer station would be approximately $147,000 as developed in table 48.

TABLE 48

ESTIMATED CAPITAL COSTS FOR INSTALLATION OF MEDIUM-SIZE PRESS

	Estimated cost
Site preparation and alterations to existing building	$7,000
Delivered cost of purchased equipment	82,000
Installation cost including electrical	16,000
Mobile crane with orange peel grapple	20,000
Installed cost of physical equipment	125,000
Engineering	10,000
Field inspection/construction management	2,000
Contingency	8,000
Escalation to December 1967	2,000
Total estimated project cost	147,000

The above estimate provides for installing the press on concrete piers in trailer stall no. 4 with the hydraulic system and control station located in the adjacent storeroom space on the operating floor level as shown in figure 8.

The estimated cost of installation of a large size press in a separate building at the incinerator plantsite would be approximately $255,000, as developed in table 49.

TABLE 49

ESTIMATED CAPITAL COSTS FOR INSTALLATION OF LARGE PRESS

	Estimated cost
Site preparation, foundation, and building	$34,000
Delivered cost of purchased equipment	129,000
Installation cost including electrical	18,000
Mobile crane with orange peel grapple	31,000
Installed cost of physical equipment	212,000
Engineering	11,000
Field inspection/construction management	5,000
Contingency	16,000
Escalation to December 1969	11,000
Total estimated project cost	255,000

The above estimate provides for the installation of the large press at an independent location in the immediate vicinity of Incinerator Plant No. 5 as shown in figure 9. The estimate does not include the furnishing of electric power to the site, toilet and locker room facilities, or site development such as access roads, grading, or landscaping. The estimate does take into account the need for piling under the heavy equipment due to anticipated poor soil conditions. The building to house the hydraulic and control equipment would be a brick and steel frame structure erected above grade level. Electrical work included in the estimate originates at a disconnect switch in the control building.

ESTIMATED OPERATING COSTS

As indicated above, each press would require four men to operate it. The following table indicates the annual payroll costs for these four men, including allowances for vacation, retirement, and overhead:

Job classification:	*Annual wages*
Crane operator	$8,000
Truck driver	7,500
Press operator	7,100
Laborer	6,000
Gross labor cost	28,700

It has also been previously stated that each press could handle from 5 to 20 tons of metal per hour. Due to the extreme bulkiness of the scrap to be handled it has been assumed that the lower figure would be typical of the performance that could be exepcted from each press. If the gross annual load to be handled is in the order of 3,750 tons a year, only 15 tons per operating day would require handling. Allowing some time each day for starting up and cleaning up, only 4 hours of operation of one press are required to handle the entire load. If both presses are used, only 2 hours per day on each would be required. Men from the transfer station and/or the incinerator regular operations could be used part time to handle the bulky metal objects. For this reason, operating labor costs based on the hours actually expended will be used in the operating cost estimate.

Included in the following tabulation of operating costs are electric power and fuel costs and maintenance costs prorated according to the hours of operation. Fixed charges are based on the capital investment being paid off over a 10-year period at an interest rate of 4.5 percent per annum.

The table on the following page lists operating costs for each press on the basis of 2 hours, 4 hours, and 8 hours per day operation. If both presses were used 2 hours per day to handle the anticipated load of 15 tons per day, the cost would be $20 per ton. However, if only the smaller press were installed and it were operated 4 hours per day, the cost would drop to $11 per ton.

APPENDIX B

Representative List of Manufacturers of Hydraulic Press Equipment

D. and J. Press Co., Inc., North Tonawanda, N.Y.
Dempster Bros., Inc., Knoxville, Tenn.
Harris Press and Shear Co., Cordele, Ga.
Logemann Bros., Inc., Milwaukee, Wis.

TABLE 50

ANNUAL OPERATING COSTS

	Transfer station press			*Incinerator No. 5 press*			*Combined operation*
	2 hours per day	4 hours per day	8 hours per day	2 hours per day	4 hours per day	8 hours per day	2 hours per day
Tons of bulky metal objects per day	7½	15	30	7½	15	30	15
Tons of bulky metal objects per year	1, 875	3, 750	7, 500	1, 875	3, 750	7, 500	3, 750
Capital investment	$147, 000	$147, 000	$147, 000	$255, 000	$255, 000	$255, 000	$402, 000
OPERATING COSTS							
Labor	$7, 200	$14, 350	$28, 700	$7, 200	$14, 350	$28, 700	$14, 400
Electric power and fuel	$2, 000	$4, 000	$8, 000	$2, 000	$4, 000	$8, 000	$4, 000
Maintenance	$2, 200	$4, 400	$8, 800	$3, 800	$7, 600	$15, 200	$6, 000
Direct operating costs	$11, 400	$22, 750	$45, 500	$13, 000	$25, 950	$51, 900	$24, 400
Annual fixed charges	$18, 600	$18, 600	$18, 600	$32, 400	$32, 400	$32, 400	$51, 000
Total annual operating cost	$30, 000	$41, 350	$64, 100	$45, 400	$58, 350	$84, 300	$75, 400
Processing cost per ton	$16	$11	$9	$24	$16	$11	$20
Cost per operating day	$120	$165	$256	$181	$233	$337	$301

heat recovery

ABSTRACT

SEVERAL apparently successful European applications of steam boilers to municipal refuse incinerators have prompted consideration of similar installations for American incinerators. American operating experience with incinerator heat recovery boilers has been limited, and no outstanding pattern of successful operation has been established.

In order to evaluate this disparity between European and American practice, this report compares the typical refuse compositions, refuse heating values, and the applications of heat recovery equipment to incinerator furnaces.

Consideration is given to both refractory and water-cooled furnaces, their effect on excess air requirements, and the economics of the sale of steam or other methods of heat dissipation.

For the proposed Washington, D.C., Incinerator No. 5, the report reviews the application of a boiler plant capable of burning 800 tons of refuse per day with four incinerator furnaces. The economics of the proposed plant do not justify the installation of heat recovery equipment.

INTRODUCTION

THERE HAS BEEN considerable discussion recently regarding the application of heat recovery equipment to municipal refuse incinerators. Many industrial publications list accounts of refuse incinerator boiler units installed in European cities where the available heat energy of municipal refuse is recovered and used for the generation of steam. In contrast there are relatively few such units installed in the United States.

There is a considerable difference of opinion in the United States as to the justification for installation of boiler units on municipal waste incinerators. This study has been conducted to determine what factors should influence the decision to install heat recovery equipment and what performance and maintenance conditions can be anticipated.

Our analysis included studies of the following items to determine their effect on performance and operating costs: Refuse composition, ultimate analysis, and heating value; relative characteristics of refractory and water cooled furnaces; specific design requirements of boiler convection surfaces suitable for use with incinerator furnace gases; the effect of heat recovery equipment on flue gas volume due to a reduction in excess air requirements and a reduction by convection cooling as compared to spray water cooling; the effect of steam demand requirements on incinerator operation; and, the effect of variations in refuse moisture and furnace excess air on steam production rates.

All of the above factors were applied to the operation of representative types of incinerator boiler units. Four basic configurations of furnace, boiler, and exit gas cooling were separately evaluated.

SUMMARY AND RECOMMENDATIONS

The composition of refuse reported in literature as fired in European plants is characteristically lower in combustible material and heating value than American refuse. U.S. refuse shows a reasonable amount of uniformity in composition between equivalent metropolitan areas.

The higher percentage of paper and plastic products in American refuse is believed to explain a significant additional carryover of ash and potentially corrosive materials which are deposited on boiler tube surfaces. Both European and U.S. experience indicates that boiler tube damage has resulted from these deposits. Modern refuse also contains products which are known to burn to corrosive gases. The presence in the refuse of large quantities of ash, as in Europe, provides a material which can absorb and neutralize some of these corrosive products.

Modifications to standard boiler designs will help to reduce the accumulations of incinerator furnace ash on the boiler tubes. These modifications, combined with improved cleaning procedures and protection of

PRECEDING PAGE BLANK

boiler surfaces against dew-point condensation, should reduce loss of tube metal.

Most refractory incinerator furnaces are operated at excess air levels of 150 percent or greater. Waterwall furnaces in Europe are reported to operate at excess air levels as low as 50 percent but there is reasonable doubt these lower levels are obtained without firing of auxiliary fuels such as oil or pulverized coal. There is no operating experience with waterwall furnaces in the United States to evaluate the potential of operation at lower excess air levels with municipal refuse.

The generation of steam in a municipal refuse incinerator plant cannot be reasonably varied to meet seasonal load conditions, unless the plant is provided with boiler bypass flues or steam condensing equipment. Economical operation usually requires that the plant be part of a large steam generating system.

Plant auxiliaries are affected by the type of installation and operation selected. These include storage pit capacity, air pollution control equipment, and fan sizes. Steam generating capacity is influenced by the type of furnace, the amount of excess air, and the moisture content of the refuse. Auxiliary fuel firing is recommended where steam is sold or a minimum steam production is required.

A cost comparison of four different incinerator and incinerator boiler arrangements indicates that the lowest annual operating expense is usually anticipated with a conventional refractory furnace design. Plants incorporating steam boilers can be operated at lower annual expenses than a conventional incinerator plant only if a firm market can be obtained for all of the steam production at rates high enough to cover the additional operating expenses. A waterwall furnace designed to permit operation at low excess air levels costs slightly more to install and operate than a refractory wall furnace.

The installation of water-cooled furnaces or steam boilers in the proposed No. 5 Incinerator plant is not recommended for the following reasons: (1) The anticipated operating expense of water-cooled furnace installations is higher than the refractory furnace type. (2) The trend of refuse composition toward additional plastics, freons, etc., will probably increase the existing critical metallic tube maintenance from corrosive products of combustion with insufficient assurance that present technology can deliver a boiler design that will be satisfactory for the present trends of refuse composition. (3) Reductions in operating economies, capital costs, etc., resulting from the lower gas velocities potentially available with lower excess air operation are not sufficiently assured to warrant consideration of water-cooled furnaces without an employable market for the recovered heat. (4) There is no apparent market for the sale of steam produced in this plant. (5) Successful operation at the lower excess air levels recommended for water-cooled furnace installations has not been proven.

REFUSE COMPOSITION

The composition of refuse burned in a municipal incinerator can vary to some degree with the economic living standards in the area, with the seasons of the year, and with the specific weather conditions on the particular day the refuse is collected. Reference to published data on refuse composition must be made with caution as the methods of sampling, analysis, and reporting vary between individual reports.

Three refuse analyses, each using two different methods of expressing the bulk composition of refuse, have been tabulated (table 51). The analysis of the Washington refuse has been assembled from data published in the Division of Sanitation ***Annual Report of Collection and Disposal*** for the fiscal years 1965 and 1966 and from supplementary discussions with the Sanitation Division. The analyses of a typical refuse composition for an American municipality is based on a report by Kaiser (*1*). The analysis of a typical European municipal winter refuse is based on work by Eberhardt (2, 3).

As indicated by a comparison of the analyses in table 51, European refuse contained a higher percentage by weight of garbage, water, ash and noncombustible trash than American refuse. This was apparently due to a lower percentage of paper and wood products in European refuse.

The higher moisture and ash content of European refuse significantly lowers the heating value and reflected a need for auxiliary fuel burners to maintain ignition.

Kaiser in his work on chemical analyses of refuse components presented data on the "proximate" and ultimate analyses of 20 components of municipal refuse (*1*). This author also reported a breakdown of the probable constituents of this refuse on a percentage basis by weight of the total refuse.

This data was applied to available information on Washington refuse and the following ultimate analysis for the refuse composite was developed.

	Percent
Carbon	27.6
Hydrogen	3.8
Oxygen	24.5
Nitrogen	.3
Sulfur	.1
Water	20.0
Ash	23.7
Total	100.0

This ultimate analysis on a 20 percent moisture basis results in a heating value of 5,069 Btu per pound of refuse.

This analysis and heating value was used for the calculation of combustion air requirements, flue gas analyses, furnace temperatures, heat transfer, and steam generating capabilities of the furnace configurations included in this study.

The procedure used to determine the above ultimate analysis can be followed wherever a reasonable estimate of the composition by components of the refuse is available. Application of the weighted percentages of the refuse components to the ultimate analyses reported by Kaiser (*1*) will produce an equivalent ultimate analysis.

The analysis prepared for the previous section, entitled, *Study of Municipal Incinerator Effluent Gases*, was modified to forecast the future probability of additional plastics in the refuse and therefore shows a slightly different ultimate analysis.

Appendix C presents an analysis of a typical municipal refuse patterned after the report by Kaiser (*1*). Included in this table are the ultimate analyses of components useful in the development of a composite analysis.

EFFECT OF INCINERATOR OPERATION ON BOILER PERFORMANCE AND DESIGN

Products from the combustion of incinerator refuse are known to affect boiler operation and maintenance both in the United States and Europe. These products include clay fillers of papers and plastics; salts of sodium, potassium and calcium; silicates, acids from the combustion of freons (pressurized cans), unburned hydrocarbons (soot), and water vapor.

Local zones of combustion of dry refuse with zero excess air permit theoretical refuse bed temperatures in excess of 3,700° F. Actual temperatures attained are sufficient to volatize a significant quantity of material. Fuel bed and furnace gas velocities are generally sufficient to convey the volatilized material and the low density particles to and beyond the furnace exit. Any obstructing surface, such as a convection boiler tube, can receive this material by impingement. If the material is plastic or adhesive, the deposit will

TABLE 51
TYPICAL REFUSE ANALYSES

	Washington, D.C.	American municipality [1]	European municipality [2]
Refuse composition:			
Garbage ... percent	11.2	12.4	23.0
Combustible trash ... do	78.0	81.7	61.5
Noncombustible trash ... do	10.8	5.9	15.5
Refuse analysis:			
Moisture ... do	11.0	11.7	23.7
Ash ... do	26.4	22.3	41.0
Combustible ... do	62.6	66.0	35.3
Heating values:			
Refuse, as discarded [3] ... B.t.u./lb.	5,639	5,955	3,642
Refuse, dry basis ... do	6,336	6,744	4,773
Combustible material [4] ... do	10,121	9,023	10,317
Refuse at 20 percent moisture ... do	5,069	5,395	3,818

[1] The analysis of a typical refuse composition for an American municipality is based on the report by Kaiser (*1*).

[2] The analysis of a typical European municipal winter refuse is based on information in references *2* and *3*.

[3] Moisture content varies as noted above.

[4] Moisture and ash free.

accumulate. If the material is nonadhesive, erosion may occur when bare metal is exposed to nonadhering abrasive material. The rate of erosion will depend on the velocity of impingement.

Practically all of the flue-mounted convection boiler installations on incinerators in this country suffer from troublesome accumulations of deposits on the boiler tubes. In many of these installations the deposits become corrosive. During the initial stage of the deposit accumulation, the boiler steaming capacity is reduced by the insulating effect of the deposit and the boiler exit gas temperature increases. If the deposit is allowed to accumulate, the gas passages become plugged and eventually limit the available draft required to pass the gaseous products of combustion.

To avoid "positive furnace draft" or back pressure in the furnace, the undergrate airflow is then reduced, usually without reducing the refuse feeding rate. The resultant lower furnace excess air develops higher furnace and refuse bed temperatures which, in turn, develop excessive furnace slagging, clinkering, ash pit combustible loss, stack smoke, and greater furnace and stoker maintenance.

Boiler tube deposits from municipal waste incinerators are generally so cementatious that retractable soot blowers, where employed, are not adequate. Additional frequent manual cleaning during boiler shutdowns is usually required to maintain capacity operations.

Most of the existing incinerator boiler installations in the United States have been made using conventional designs of steam boilers, with relatively close tube spacing to obtain maximum steaming capacity and efficiency at minimum cost. The opportunity to accumulate deposits would be reduced if the tube spacing were increased by several inches. This change would also enable more effective cleaning.

This increased tube spacing should reduce loss of boiler capacity and availability but will significantly increase boiler costs and reduce the steaming capacity and efficiency. A design allowance for a 640° F boiler exit gas temperature should obtain a useful installation without excessive additional cost.

The overall operating experience at several East Coast installations (appendix D) indicates that the boiler inlet gas temperature should be below 2,000° F (1,800° F maximum appears tolerable) and that the flame travel pattern should be long enough to avoid impingement on the convection tubes. This should permit solidification of enough of the molten or adhesive particles to adequately reduce the slagging or deposit accumulating rate to within the range controllable by the boiler tube spacing design. If lower furnace exit temperatures are obtained with additional furnace excess air, the increased gas velocity increases the furnace particulate emission rate, the boiler draft loss, and the required forced and induced draft fan capacities. All of these conditions will increase the rate of any erosion and the rate of deposit accumulations.

The alternative to lowering furnace exit temperatures by additional furnace air, is the addition of furnace wall cooling. Radiant heat absorption by the furnace walls can reduce the furnace temperatures so as to enable operation at significantly lower excess air levels. This in turn will reduce the furnace particulate emission rate, the boiler draft loss, and the required fan capacities. All of these conditions associated with a water-cooled furnace should reduce the rate of convection boiler tube erosion and deposit accumulations.

Water-cooled furnaces have been in service for several years in European incinerators, with refuse conditions and operating levels different from those employed in the United States. Several American installations using water-cooled furnaces are currently being considered and one is about ready for initial service (*4*). It should be noted that no satisfactory operating experience record has been developed on this type of plant in the United States. The experience reported from the limited operations of the water-cooled nonsteam generating furnace installations at Framingham, Mass., and Whitemarsh Township, Pa., is not useful for evaluating the steam generating heat recovery type of operations being considered in this report.

The available design information for water-cooled furnace installations indicates that a minimum tube temperature of 400° F is required to avoid external tube corrosion, and that auxiliary fuel burners will probably be required to maintain ignition of wet or low heating value refuse. Tube corrosion of a more complex nature is also known to occur at metal temperatures above 750° F (2, 3). The chlorides and fluorides from the combustion of polyvinylchloride plastics and from the incineration of freons in pressurized cans can cause extensive damage to metal surfaces in the incinerator.

In addition to the direct action from the products of combustion, a severe dew-point corrosion potential exists in incinerator furnaces. The total moisture content of the gaseous products of combustion result-

BLANK PAGE

ing from the combined effects of the moisture content of the refuse, the moisture produced by the combustion of hydrogen in the fuel, and the moisture in the combustion air creates a dew-point condition which may react with the products of combustion to develop corrosion on any exposed metallic surfaces at temperatures of less than 400° F (*4*, *5*). Although there may be few such critical spots during normal operation, all boiler tube surfaces may be exposed to dew-point condensation and corrosion during low burning periods and boiler startup or shutdown operations. The hygroscopic nature of some boiler tube deposits tends to aggravate this condition during boiler shutdowns.

To minimize this dewpoint corrosion, the tube metal temperatures need to be held above the gas dewpoint with auxiliary furnace heat or with steam circulation during low temperature operating conditions, or the hours of such exposure must be held to a minimum. This preventive maintenance is not generally practiced in American incinerator boiler plants.

EFFECT OF BOILER OPERATION ON INCINERATOR PERFORMANCE AND DESIGN

In order to evaluate the feasibility of the equipment arrangements available to designers of incinerator boiler plants, it is necessary to consider the effect of the boiler on the overall operation of the plant.

The primary purpose of an incinerator plant is the reduction in volume and combustible content of the refuse to permit maximum utilization of landfill space for the disposal of the ash residue. The incineration process must be conducted in a manner which will minimize pollution of the atmosphere and limit pollution of the ground and water sources from contact with the ash residue.

These conditions cannot be obtained without adequate incineration of the combustible content of the refuse in a furnace atmosphere that provides the necessary temperature to insure acceptable burnout of the residue and the gaseous products of combustion.

Typical incinerator operating practice in the United States is maintained with excess combustion air of 150 to 200 percent in refractory furnaces to obtain satisfactory burnout of the refuse and acceptable furnace temperatures. The use of a water-cooled furnace requires a reduction in excess air to approximately 50 percent to maintain the necessary furnace ignition and exit temperatures. The effect of this reduction in excess air on the burnout of the refuse and flue gases has not been determined in plants burning U.S. refuse. The excess air quantities for incinerator operation in European plants are reported (2, 3) to be 50 to 70 percent with water-cooled furnaces having widely amounts of supplementary firing of fuel oil and pulverized coal. No definite trend of excess air requirements has been obtained from published data on European operations.

A few attempts have been made in the United States to operate continuous feed incinerator grates in refractory furnaces at low excess air levels; these resulted in heavy slag accumulations on the furnace sidewalls and refuse clinkering. It has been reported (*6*) that the operation of the Issy-les-Moulineaux water-cooled furnace incinerator plant in Paris is conducted at 90 to 100 percent excess air. This report indicated that attempts to operate other plants at lower excess air levels have been unsatisfactory (*6*). This lack of encouraging experience with lower excess air operation—and the indication that satisfactory burnout of American refuse is obtainable only with undergrate excess air levels above 100 percent and furnace outlet excess air levels above 150 percent—practically specifies a minimum 150 percent excess air design for any new incinerator application.

The primary purpose of most steam generating plants is to produce a quantity of steam that varies with the demand. Seasonal loads for heating and air conditioning, combined with daily and weekly variations in process steam loads, create varying load conditions which are readily compensated for in a normal fuel fired installation by a variation in the fuel firing rate. In contrast, the steam production capability from an incinerator boiler will vary with the instantaneous available heat from the burning refuse. Steam production charts from refuse fired incinerator boilers show rather wide variations in the quantity of steam generated when the unit is operated with a steady refuse feeder speed and fixed airflow dampers. See the section of this report, *Factors Affecting Steam Generating Capacity*. For a controlled boiler steam output, auxiliary fuel firing is required to compensate for the varying usable heat from refuse in the furnace. The average daily steam production, either with or without auxiliary fuel firing, umst correspond to the rate at which refuse must be incinerated. It is impractical to store large quantities of refuse for several weeks or months to meet winter peak steam demands.

The installation of an incinerator refuse boiler as the only source of steam to be sold at commercial rates must provide for auxiliary firing to meet maximum steam demands if wet refuse or lack of refuse begins to limit production. In addition, the plant must be provided with steam condensing facilities or boiler bypass flues to handle excess steam production capability when steam loads are limited.

The most practical installation of an incinerator boiler unit is as part of a large system where the minimum steam demand is greater than the capacity of the incinerator boiler units. Under this condition the momentary variations of steam output will not upset system pressures. Also, minimum steam demands will not require wasting of the steam production from the incinerator boilers. It is interesting to note that most of the European incinerator boiler plants reported in literature supplement steam from other sources in this manner.

The design of refuse storage facilities and selection of incinerator furnace sizes must consider the needs of the steam generating equipment. A plant designed to receive an average of 800 tons per weekday of municipal refuse would receive 4,000 tons of rufuse per week of 5-day refuse collections. Burning this material over 7 days would require an incinerator-boiler total capacity of approximately 575 tons per day. This would represent three incinerator-boiler units of approximately 200-tons-per-day capacity each. A fourth unit would be required as standby to permit the plant to meet steam demand requirements if one unit is out of service. This results in a total installed capacity of 800 tons per day even though the plant is operating 7 days a week.

The storage pit of an incinerator boiler plant must be capable of holding sufficient refuse to maintain operations at rated loads from the end of refuse deliveries on Friday afternoons (approximately 4 p.m.) to the beginning of refuse deliveries on Monday morning (approximately 9 a.m.). This represents approximately 65 hours of refuse storage. On the other hand, the storage pit of a plant designed for 5-day, 24-hour operation must be capable of holding sufficient refuse to maintain operations at rated loads for approximately 17 hours. Conversion of these hours of operation to tonnage figures indicates a refuse storage bin requirement approximately 2.7 times larger for the incinerator boiler plant, operating 7 days per week as compared to an incinerator plant operating 5 days per week. This has a significant effect on the capital investment requirements.

Manpower requirements of an incinerator boiler plant are normally greater than an incinerator plant. In most States, licensed boiler operators are required because of the operation of fired pressure vessels. In addition, the plant will require additional personnel to operate and maintain necessary water treating equipment, steam condensing equipment, boiler feed pumps, auxiliary firing equipment, a deaerating heater, condensate pumps, etc. This represents a substantial increase in operating labor over the normal incinerator operation. The plant is also committed to a more rigid schedule with 7 days per week, 24 hours per day, utility type operation. This is more demanding on the plant management and personnel.

FACTORS AFFECTING STEAM GENERATING CAPACITY

The steam generating capability of an incinerator boiler combination is noticeably affected by both moisture in the fuel and the excess air used to burn the refuse.

The moisture in the fuel is beyond the control of the plant operator as it is determined by the manner in which the refuse is discarded, protected from the weather (rain and drying winds), and collected. Additional moisture is occasionally added by the plant operators in the storage bins to control dust. Momentary variations in the refuse are determined by the amount of garbage, grass clippings, etc., present as the refuse is burned. Figure 10 shows the variations in steam generating capacity with moisture content of the refuse for two furnace conditions.

An increase in moisture content from 10 to 20 percent can reduce the steam generating capacity 26 percent (from 1.9 to 1.6 lbs. of steam per pound of refuse) in a refractory furnace with a flue-mounted boiler operating at 200 percent excess air. The corresponding change in a water-cooled furnace installation operating at 60 percent excess air is an 18-percent decrease (from 3.3 to 2.8 lbs of steam per lb of refuse) (fig. 10).

Coupled with the changes due to mositure content are changes due to excess air variations. With conventional incinerator operation, the furnace draft is maintained constant. The airflow through the refuse bed is the resultant of the average back pressure developed by the depth, density, and porosity of the refuse and the volume-pressure characteristics of the forced draft fan. The variations in the total undergrate airflow can be either gradual or sudden and usually frequent because of the varying refuse bed conditions.

The actual refuse feeding rate in pounds per minute varies widely because of varying refuse density, even

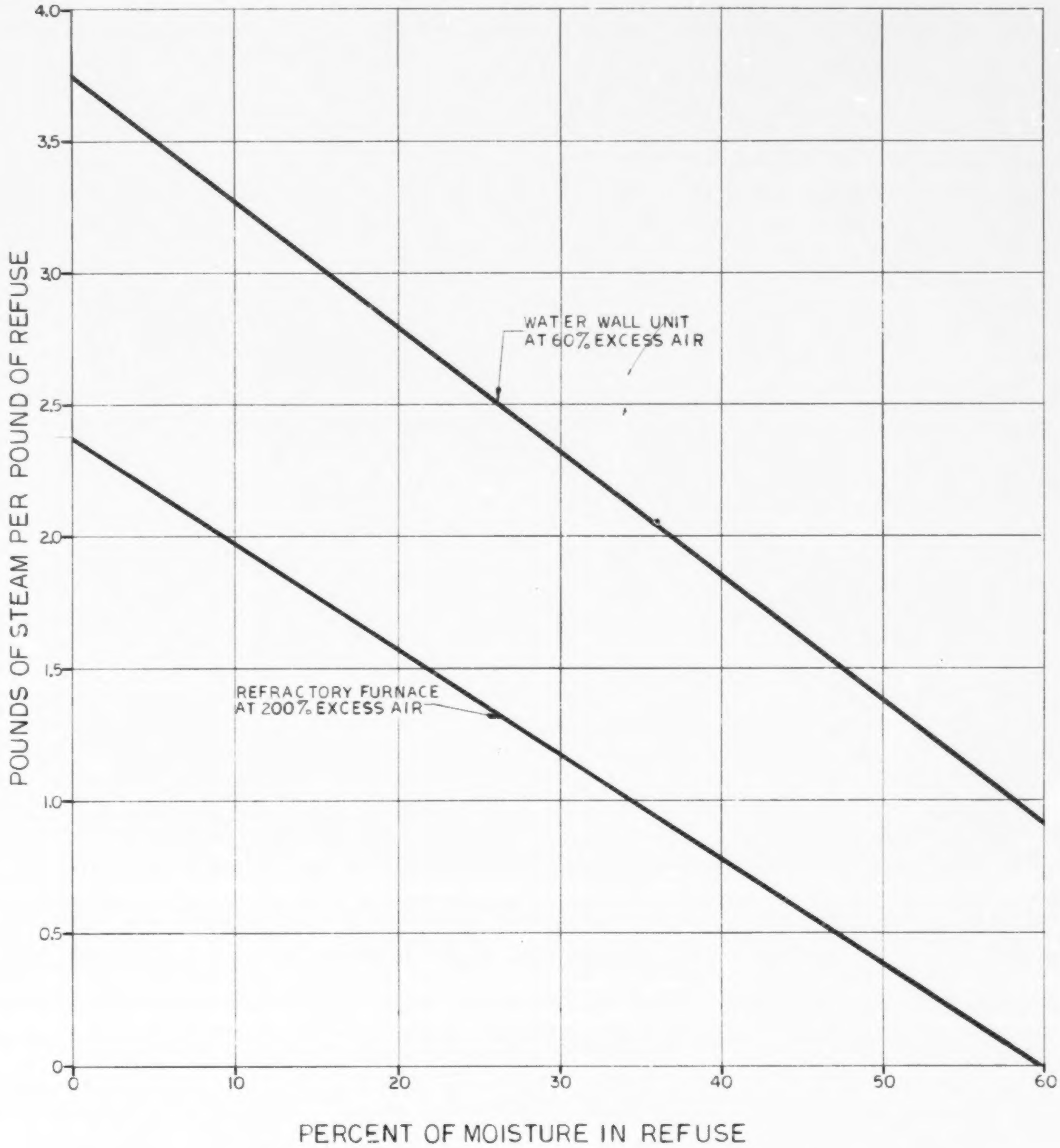


FIG. 10. *Effect of refuse moisture on steam generating capacity.*

though the cubic feet per minute may be constant. This variation in feeding rate, combined with wide variations in the heating value of the material being charged (such as changes from wet garbage to free burning plastics), can cause considerable variation in the steam generating rate.

The undergrate combustion excess air that results from the varying airflow and combustible content of the refuse varies haphazardly and frequently over a range of 10 to 50 percent of the excess air from the average condition.

An increase in excess air of 50 percent (from 150 to 200 percent) in a refractory furnace flue-mounted boiler can reduce the steam generated per pound of refuse by 11 percent (from 1.8 to 1.6); the corresponding change in a water-cooled furnace unit for an increase of 50 percent excess air (from 50 to 100 percent) is 7 percent (from 2.8 to 2.6) (fig. 11).

As a result of variations in moisture, excess air, combustible feeding rate, and heating value of the combustible in the refuse, the steam generating capacity of an incinerator-fired boiler without auxiliary firing can haphazardly vary from approximately zero to 3.5 pounds of steam per pound of refuse fed.

If a constant steaming capacity is required from the plant, auxiliary fuel burners with adequate capacity, instantly available, are required.

Effect of Boiler Installation on Air Pollution Control Equipment

The proper size of air pollution control equipment is determined by both the method of operation of the furnace (excess air) and the method of gas cooling

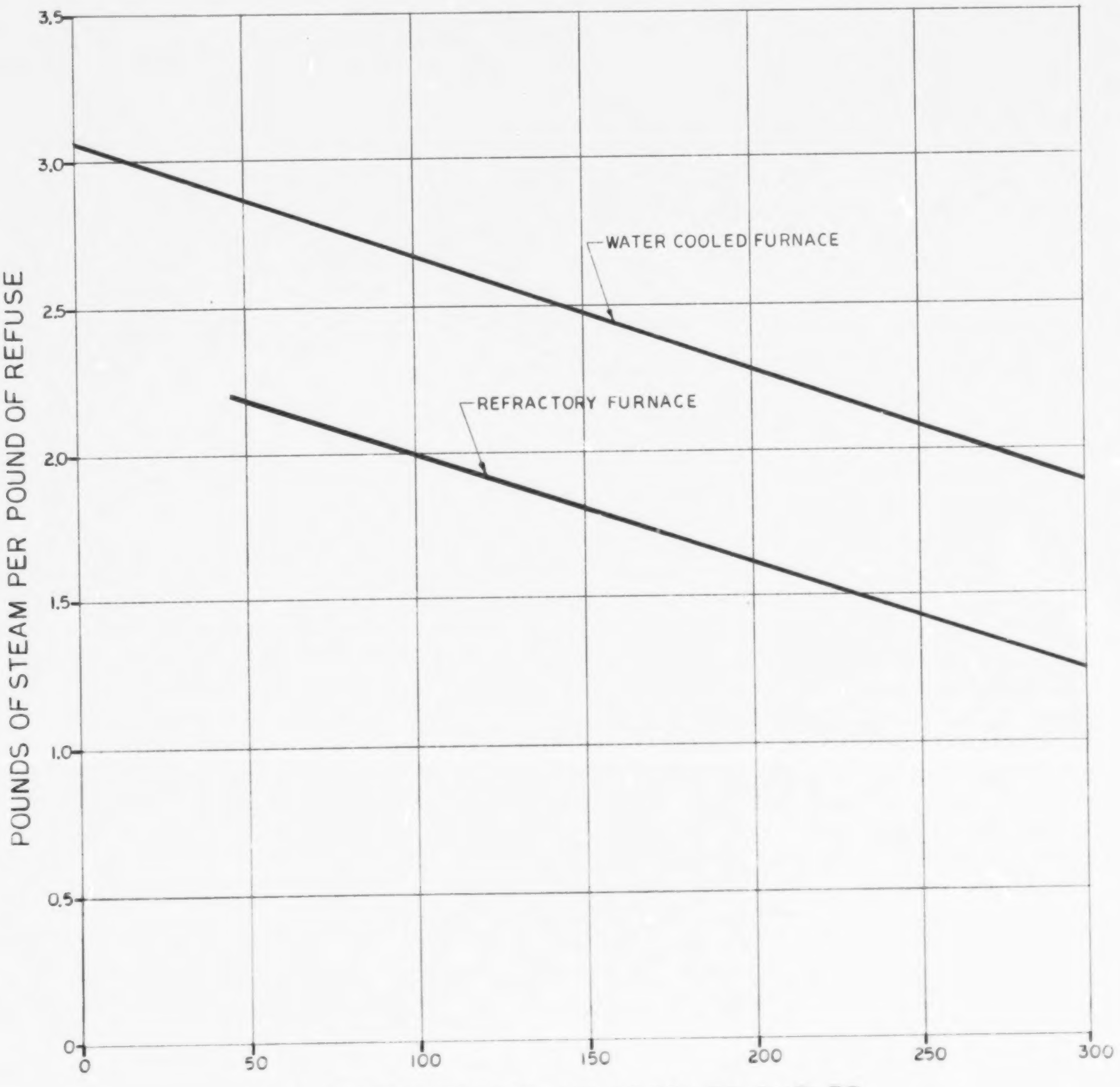


Fig. 11. *Effect of excess air on steam generating capacity.*

(boiler, spray water cooling, or cooling by air dilution). Evaluation of capital and operating costs requires that these factors be considered in the selection of the equipment.

The excess air requirements used for design of water-cooled and refractory wall furnaces are selected to obtain a furnace exit temperature below 1,800° F for entry into the boiler convection surfaces. We have calculated the volume of the products of combustion of a water-cooled furnace designed to operate at 60 percent excess air and a refractory walled furnace designed to operate at 200 percent excess air. These curves are appropriate only for a specific design and will vary with the heat absorption of the refractory or waterwall furnace enclosures. The changes in volume due to additional cooling of these gases by various methods is shown graphically in figure 12. The exit gas volume of the water-cooled furnace will be approximately 120,000 c.f.m. as compared to 165,000 c.f.m. leaving the refractory furnace. This difference is due to the different amounts of excess air used in the two furnaces.

The gases leaving the furnaces can then be additionally cooled by passing them through a boiler. The resulting boiler exit volumes are 60,000 c.f.m. and 105,000 c.f.m., respectively, at a temperature of approximately 640° F.

If the furnace gases are discharged through a boiler bypass with spray cooling to reduce the temperatures, then the final gas volumes will be greater than those of the gases cooled by a boiler. These volumes will be approximately 125,000 c.f.m. and 82,000 c.f.m., respectively, at a temperature of 640° F.

The capacity of the dust collector for this particular application may vary between 60,000 and 125,000 c.f.m., depending upon the details of the incinerator boiler installation.

The use of dilution air for cooling produces an excessive volume of flue gas (as shown in fig. 12 by the broken line). The corresponding dust collector capacity for a refractory furnace installation using air dilution cooling would be approximately 260,000 c.f.m., requiring a dust collector four times the size of the unit for a waterwall furnace and boiler combination.

DESCRIPTION OF EQUIPMENT ARRANGEMENTS

We have included in this study four basic configurations of incinerator furnaces and boilers. These have been selected to cover the major variations of incinerator boiler combinations. These four are briefly described as follows: Case I: Conventional refractory furnace with spray cooling of flue gas; Case II: conventional refractory furnace with spray cooling of flue gas and boiler in by-pass flue; Case III: waterwall furnace with convection boiler; and, Case IV: waterwall furnace with spray cooling of flue gas.

Each case was studied to determine operating characteristics, steam production capability, and annual owning and operating costs.

Included in the capital cost estimates for each of the arrangements are all items of equipment and structure which are considered to vary between any of the arrangements. All equipment is considered to be fully enclosed within structures of comparable unit cost, with the size of the structure varied to suit the space requirements of the equipment. Adjustments in cost were made for pit capacity required for 7-day operational steam-producing plants to permit storage of refuse adequate for continuous operation from Friday afternoon to Monday morning. The sizing and cost of auxiliary equipment such as cyclone dust collectors, electrostatic precipitators, and fans has been adjusted for the gas volume resulting from operation of the specific type of unit. These and other considerations are discussed in the following case descriptions:

CASE I

The Conventional Refractory Furnace with Spray Cooling of Flue Gas.—This furnace type is included in this study as the base for comparison with steam producing and water-cooled furnace designs. It is shown schematically in figure 13. It has been assumed that this plant will contain four, 250-ton-per-day incinerator units, with a maximum installed capacity of 1,000 tons per day. Our study is based upon normal operation of the four units at 80 percent of load for a total plant capacity of 800 tons per day for 5 days, equivalent to 4,000 tons per week. Overcapacity of the units has been provided to permit the plant to process 750 tons per day with one unit out of service.

The pit storage capacity has been selected to correspond with the anticipated 800-ton-per-day operation. Manpower requirements are based upon a three-shift, 5-day-per-week operation.

It is anticipated that operation of this plant would be maintained with 150 percent excess airflow through the grates and additional overfire air to bring the furnace exit gas to a condition of approximately 200 percent excess air or 6 percent CO_2.

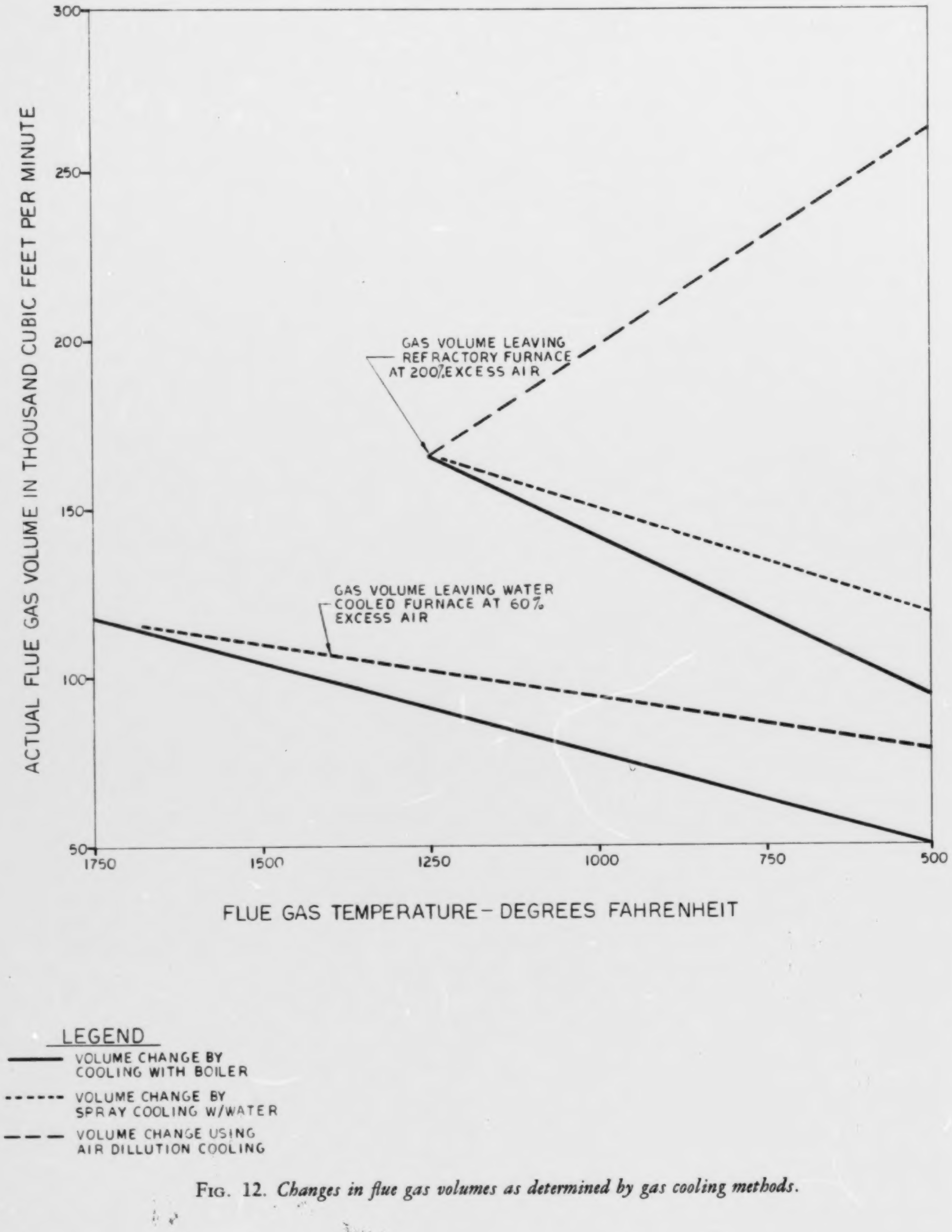
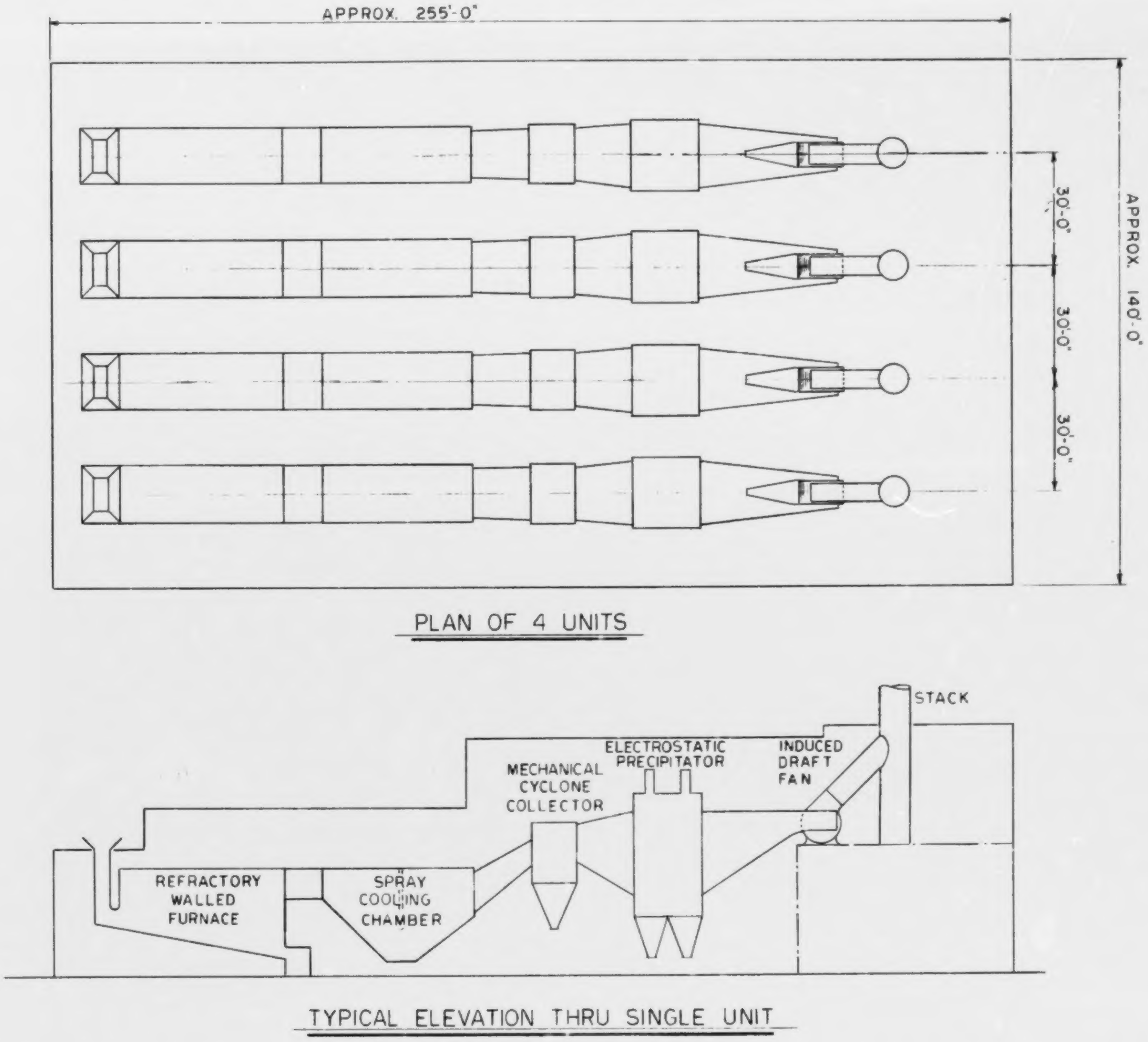


Fig. 12. *Changes in flue gas volumes as determined by gas cooling methods.*



PLAN OF 4 UNITS

TYPICAL ELEVATION THRU SINGLE UNIT

APPROX. 255'-0"
30'-0"
30'-0"
30'-0"
APPROX. 140'-0"
STACK
ELECTROSTATIC PRECIPITATOR
INDUCED DRAFT FAN
MECHANICAL CYCLONE COLLECTOR
REFRACTORY WALLED FURNACE
SPRAY COOLING CHAMBER

FIG. 13. *Case I. Schematic arrangement of the conventional refractory furnace with spray cooling of flue gas.*

The furnace has been selected for an average heat release of 15,000 B.t.u. per cubic foot of furnace volume. Maximum furnace temperature in the zone of active burning is calculated to be approximately 2,250° F. The gases would be at a temperature of 1,260° F. when they leave the furnace to enter the spray chamber. The exit gases from the furnace would be cooled with water sprays to a temperature of 550° F. entering the air pollution control equipment. This temperature is selected to permit the use of smaller sizes of air pollution control equipment. Electric power and water consumption for this case are based upon these conditions.

CASE II

The Conventional Refractory Furnace with Spray Cooling of Flue Gas and Boiler in Bypass Flue.—This case covers the addition of a flue-mounted, convection type, heat recovery boiler to case I and is shown schematically in figure 14. This unit would be equivalent in furnace size and operating conditions to the unit specified in case I, except that the flue gas would normally be cooled to approximately 640° F. by the boiler as indicated by the curves in figure 12. It has been assumed that this plant would sell steam; therefore, pit storage capacity and manpower requirements are based on a 7-day-per-week, 24-hour-per-day operation.

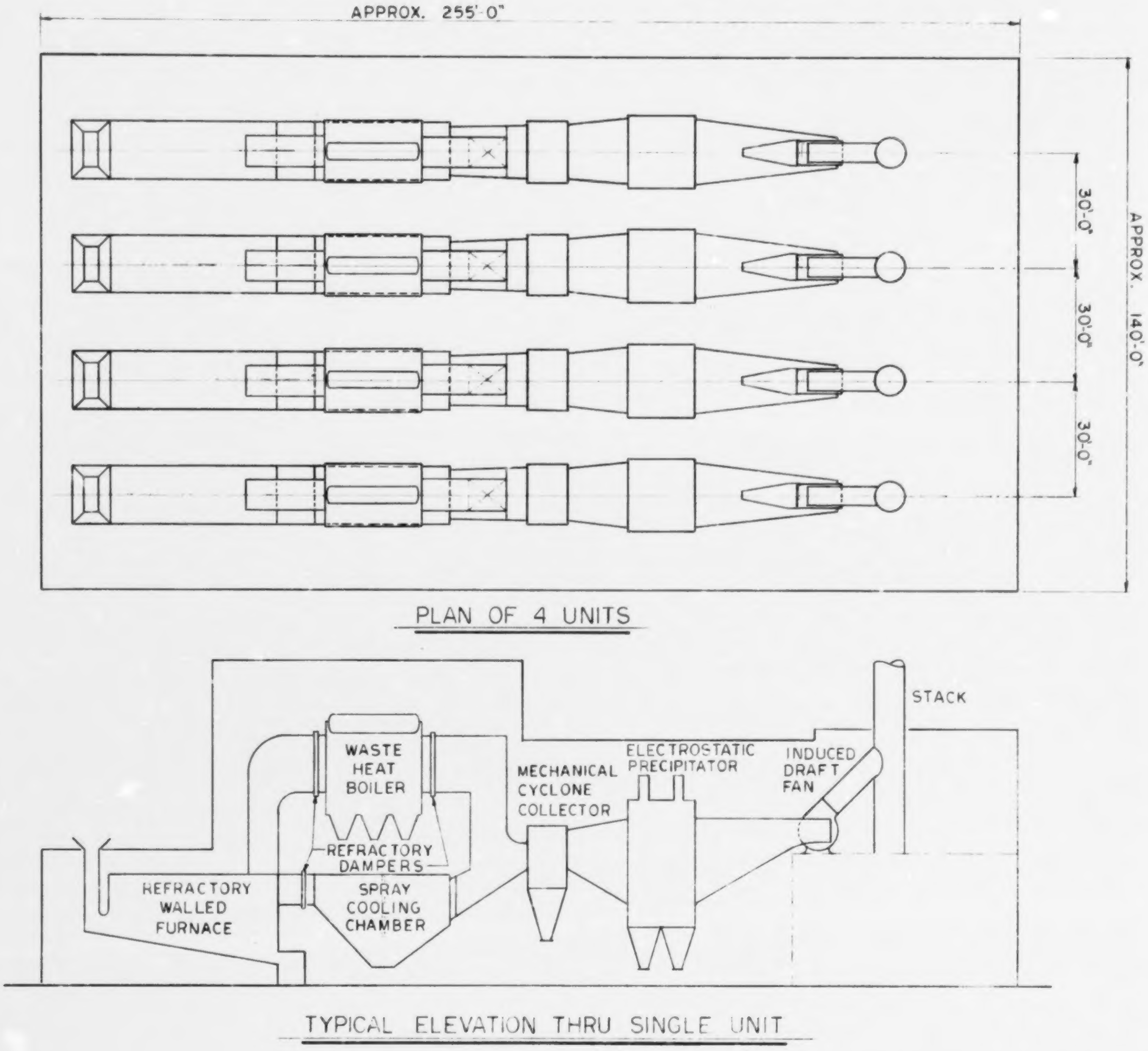

APPROX. 255' 0"
30'-0"
30'-0"
30'-0"
APPROX. 140'-0"
PLAN OF 4 UNITS
STACK
WASTE HEAT BOILER
ELECTROSTATIC PRECIPITATOR
INDUCED DRAFT FAN
MECHANICAL CYCLONE COLLECTOR
REFRACTORY DAMPERS
REFRACTORY WALLED FURNACE
SPRAY COOLING CHAMBER
TYPICAL ELEVATION THRU SINGLE UNIT

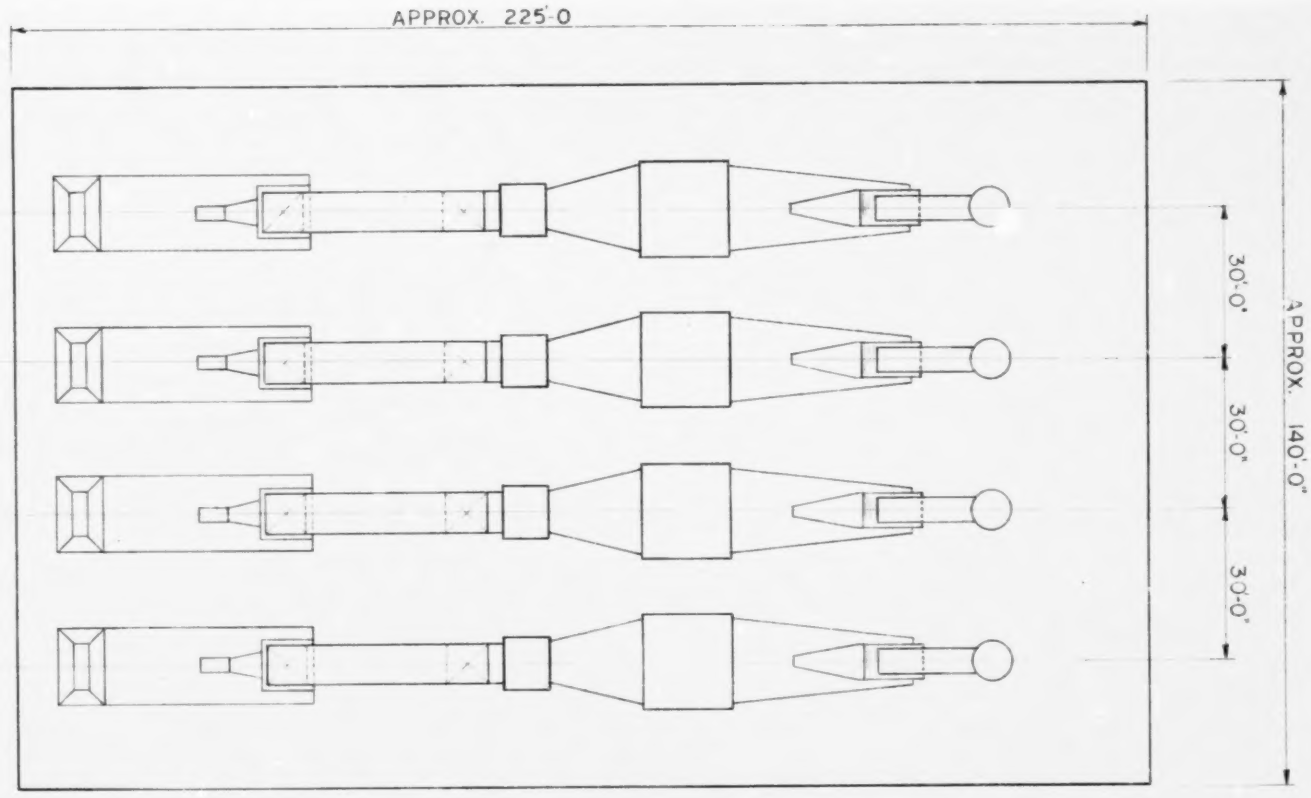
FIG. 14. *Case II. Schematic arrangement of the conventional refractory furnace with spray cooling of flue gas and boiler in bypass flue.*

Water treating and pumping equipment has been included to provide for 100 percent makeup of the water used for boiler feed requirements. The plant is provided with a bypass flue with spray cooling of the gases to permit continuous operation for burning refuse if the steam load fluctuates to meet daily and seasonal loads. Auxiliary oil burning equipment has been added to the refuse furnace to smooth out steam production rates (maintain constant boiler pressure) and to maintain steam production at the design capacity when moisture content of the refuse increases.

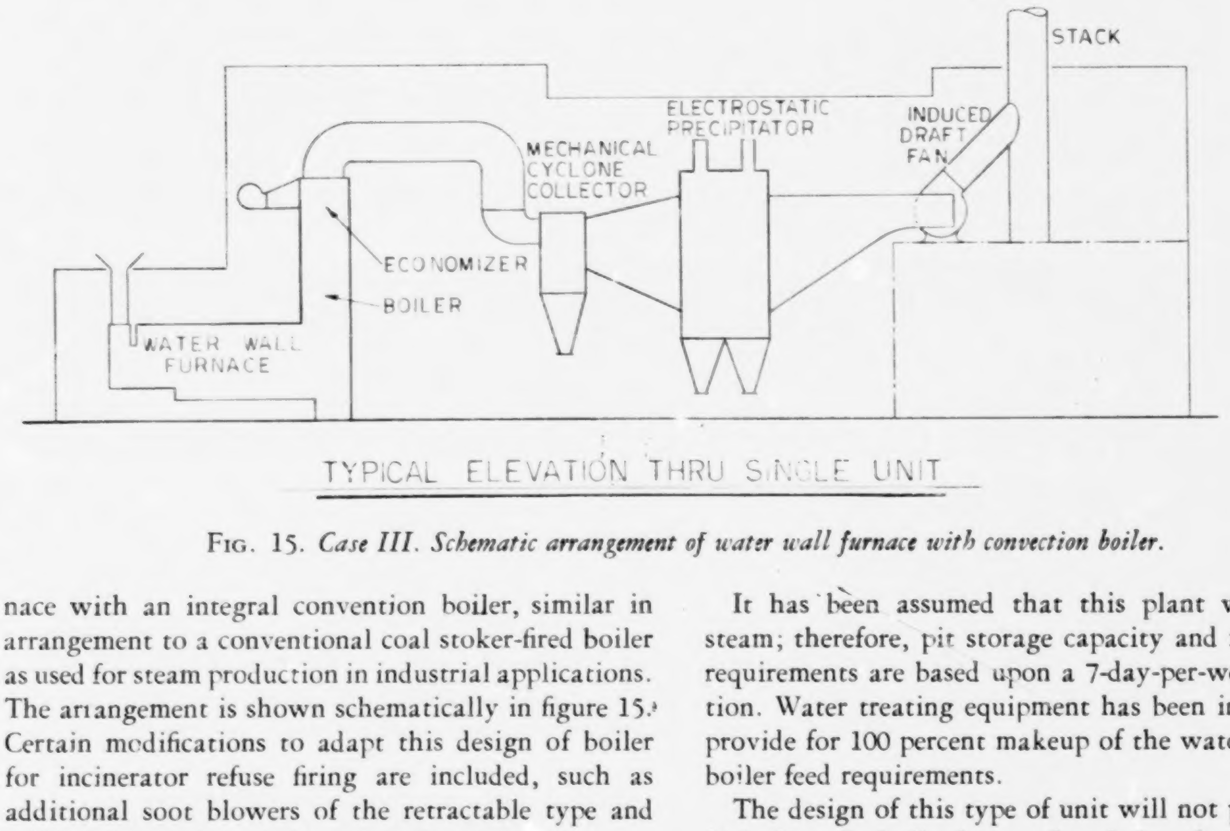
The furnace conditions would be identical to case I. The gases leaving the boiler would be of less volume and weight than the gases leaving the spray chamber of case I; however, because of the boiler bypass flue, it has been necessary to size the air pollution control equipment for the weight and volume of gas that would leave the spray cooled flue.

CASE III

The Waterwall Furnace with Convection Boiler.—This furnace is based upon the use of a water-cooled fur-


APPROX. 225'-0
30'-0"
30'-0"
30'-0"
APPROX. 140'-0"

PLAN OF 4 UNITS


STACK
ELECTROSTATIC PRECIPITATOR
INDUCED DRAFT FAN
MECHANICAL CYCLONE COLLECTOR
ECONOMIZER
BOILER
WATER WALL FURNACE

TYPICAL ELEVATION THRU SINGLE UNIT

Fig. 15. *Case III. Schematic arrangement of water wall furnace with convection boiler.*

nace with an integral convention boiler, similar in arrangement to a conventional coal stoker-fired boiler as used for steam production in industrial applications. The arrangement is shown schematically in figure 15. Certain modifications to adapt this design of boiler for incinerator refuse firing are included, such as additional soot blowers of the retractable type and wider tube spacing on the convection passes.

It has been assumed that this plant would sell steam; therefore, pit storage capacity and manpower requirements are based upon a 7-day-per-week operation. Water treating equipment has been included to provide for 100 percent makeup of the water used for boiler feed requirements.

The design of this type of unit will not permit the inclusion of a boiler bypass flue. It has therefore been necessary to include in the capital cost a 100 percent capacity steam condensing installation to permit constant burning of the refuse when steam demands are low. Auxiliary oil burning equipment has been added in the furnace to smooth out steam production rates (maintain constant boiler pressure) and to maintain steam production at the design capacity when moisture content of the refuse increases.

Furnace conditions would be different from those selected for case I and case II. The manufacturers of boiler equipment for this type of installation suggest operation at relatively low excess air rates. Our calculations are based upon 50 percent excess airflow through the grates and additional overfire air to bring the furnace exit gas to a condition of approximately 60 percent excess air or 12 percent CO_2.

The furnace has been selected for an average heat release of 19,000 B.t.u. per cubic foot of furnace volume. Maximum furnace temperature in the zone of active burning is calculated to be approximately 2,100° F. with the gases cooled to approximately 1,720° F. by the time they enter the convection surfaces of the boiler. The convection boiler would further cool the gases to approximately 640° F. before they enter the air pollution control equipment.

Electric power requirements for this case are less because of the reduced weight of flue gas resulting from operation at 60 percent excess air. Also the sizes of the air pollution control equipment and fans are significantly reduced over case I and case II equipment sizes.

Case IV

The Waterwall Furnace with Spray Cooling of the Flue Gas.—This type has been selected to include in our studies a water-cooled furnace as a replacement for a refractory furnace, as shown schematicallyin figure 16. This plant would be operated on a 5-day-per-week basis with no intent to produce steam for sale. This method of operation would permit the use of a smaller refuse storage pit. It would lower manpower requirements, reduce the use of auxiliary oil, except as necessary to maintain ignition in the water-cooled furnace, and reduce makeup water and manpower requirements.

This method eliminates the convection boiler from case III and substitutes a forced circulation water-cooled furnace with provision for spray cooling of the flue gases. The savings in capital cost over case III, resulting from the reduction in size of the refuse storage pit and the elimination of the boiler convection surfaces, are offset by capital expenditures for a spray cooling chamber and larger dust collecting equipment.

Estimated Capital and Annual Operating Costs

We have tabulated in table 52 the estimated incremental capital costs and annual operating costs for the cases described above. The capital costs include only those items that vary from one type of installation to another and do not represent total capital investment for a specific plant. The costs include contractors' overhead and profit, engineering, field supervision, and contingencies.

Annual fixed charges on the capital investments are based on a 20-year plant life and 4.5 percent interest charges. This is equivalent to equal annual charges of 7.7 percent on the capital investment.

The maintenance labor and supplies are based upon normal operating experience and provide for refractory replacement every 5 to 7 years, depending upon the location of the refractory material in the gas stream. Maintenance charges for boiler and waterwall surfaces are based on complete tube replacements every 12 years.

Operating labor varies with 5- to 7-day operation and with the need for a licensed boiler operator where pressure fired equipment is included.

City water requirements include an allowance for spray cooling of the gas stream, quenching of the ash, and makeup requirements for boiler and cooling tower operations.

Auxiliary fuel requirements include the fuel required to maintain ignition of wet refuse in water cooled furnaces and additional fuel to maintain steam production where sale of steam is required when firing wet refuse.

Electric power consumption varies primarily with the weight of flue gas resulting from different methods of operation. Electric power also varies with requirements for cooling towers and boiler feed pumps.

Operating supplies and chemicals are primarily a function of boiler makeup requirements and will vary with the sale of steam.

Value of Steam for Sale

We anticipate that the refractory furnace–boiler combination of case II should produce an average of 1.41 pounds of steam per pound of refuse. The waterwall configuration of case III should produce an average of 2.61 pounds of steam per pound of refuse when operated with an average of 60 percent

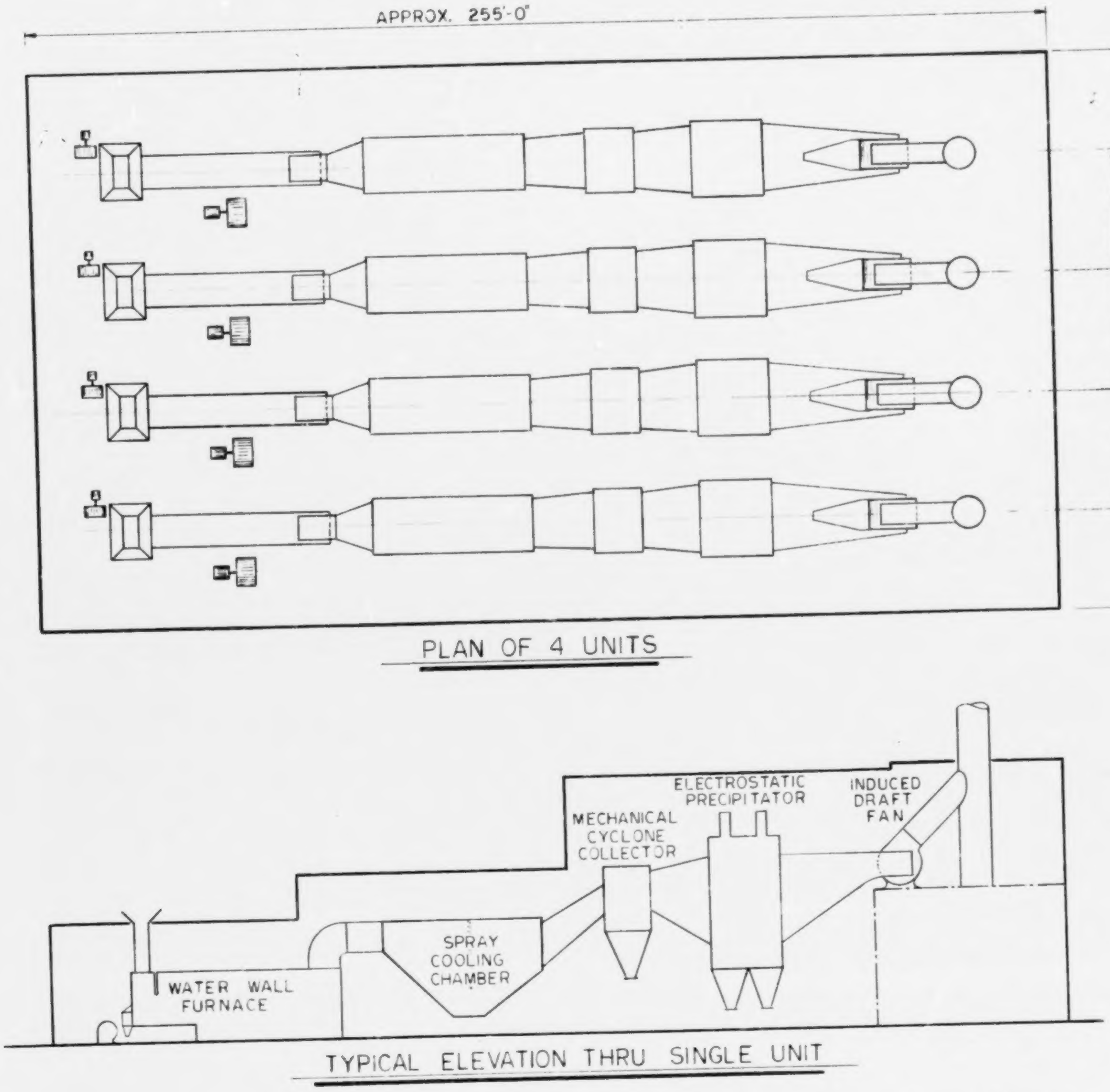

APPROX. 255'-0"
30'-0"
30'-0"
30'-0"
APPROX. 140'-0"
PLAN OF 4 UNITS
ELECTROSTATIC PRECIPITATOR
INDUCED DRAFT FAN
MECHANICAL CYCLONE COLLECTOR
SPRAY COOLING CHAMBER
WATER WALL FURNACE
TYPICAL ELEVATION THRU SINGLE UNIT

FIG. 16. *Case IV. Schematic arrangement of a water wall furnace with spray cooling of flue gas.*

excess air entering the boiler. Not all of this steam will be available for sale since approximately 16 percent of the total steam production will be consumed in the deaerating heater to heat the makeup boiler feed water.

Assuming a weekly quantity of 4,000 tons of refuse processed by the plant, and the above net production rates for steam, we have established the following values for the steam by comparison with the annual cost for case I.

Case II: $1.06 per thousand pounds available for sale;

Case III: $0.49 per thousand pounds available for sale.

These figures do not include the cost of owning and operating the steam distribution system.

These figures assume that the net steam production of the plant is sold and no steam generating capability is lost by operation of the boiler bypass flue in Case II, or by condensing operation or operation at higher excess air levels for case III. These figures can only apply where the incinerator-boiler plant at full rating is supplying less than the minimum demand of the steam system to which it is connected. Operation of

Table 52

ESTIMATED CAPITAL INVESTMENTS AND OPERATING COSTS,[1] INCINERATOR AND INCINERATOR BOILER PLANTS, REFUSE DESIGN CAPACITY—4,000 TONS PER WEEK

	Case I Refractory furnace	Case II Refractory furnace with boiler	Case III Waterwall furnace with boiler	Case IV Waterwall furnace
Capital costs:				
General building construction	$930,000	$1,215,000	$1,030,000	$938,000
Equipment delivered to site	$1,340,000	$2,620,000	$2,230,000	$2,150,000
Mechanical contract	$1,075,000	$1,580,000	$800,000	$983,000
Electrical contract	$238,000	$322,000	$237,000	$232,000
Total incremental cost	$3,583,000	$5,737,000	$4,297,000	$4,303,000
Annual operating expenses:				
Operating days per week	5	7	7	5
Maintenance labor and supplies	$140,000	$161,000	$147,000	$123,000
Operating labor	$326,000	$495,000	$495,000	$365,000
City water	$28,000	$25,000	$43,000	$30,000
Auxiliary fuel	....	$140,000	$187,000	$10,000
Electric power	$161,000	$184,000	$174,000	$161,000
Operating supplies and chemicals	$1,000	$2,000	$[illegible],000	$1,000
SUBTOTAL	$656,000	$1,007,000	$1,049,000	$590,000
Fixed charges on investment	$276,000	$442,000	$331,000	$331,000
Estimated total annual expense	$932,000	$1,449,000	$1,380,000	$1,021,000
Estimated value of steam per 1,000 pounds	....	$1.06	$0.49	....

[1] Capital investments and operating expenses include only those variables affected by plant design. They are not intended to include all costs of operation or construction at the incinerator plant.

the incinerator–boiler as the only source of steam to normal heating and air conditioning system would require a substantial increase in these cost figures.

Sale of Steam at Proposed Plantsite

An investigation was made to determine the feasibility of the sale of steam from the proposed No. 5 Incinerator plant. The Potomac Electric Power Co. operates a steam turbine powered electric generating station adjacent to the plantsite. They were contacted to determine if they could use a supply of steam from the incinerator plant at the 225 p.s.i.g. dry saturated conditions, available from an incinerator–boiler. We were advised that they could use 200 p.s.i.g. steam in their older turbines but that superheated steam was preferred. The minimum cost of steam generation at the incinerator plant plus pipeline charges is in excess of the steam generating costs for low pressure steam at the utility powerplant.

There are no other potential users in the vicinity of the plant for the quantities of steam available on a continuous basis.

appendices

Appendix C

TYPICAL MUNICIPAL REFUSE ULTIMATE ANALYSES

Refuse component		As delivered data			Ultimate analysis—dry basis				
	Percent as delivered	Percent moisture	Percent ash	B.t.u. pound	Percent C	Percent H_2	Percent O_2	Percent N_2	Percent S
1. Newspapers	10.33	5.97	1.43	7,974	49.14	6.10	43.03	0.05	0.16
2. Brown paper	6.12	5.83	1.01	7,256	44.90	6.08	47.84	0	.11
3. Magazine paper	7.48	4.11	22.47	5,254	32.91	4.95	38.55	.07	.09
4. Corrugated boxes	25.68	5.20	5.06	7,043	43.73	5.70	44.93	.09	.21
5. Plastic coated paper	.84	4.71	2.64	7,341	45.30	6.17	45.50	.18	.08
6. Waxed milk cartons	.84	3.45	1.17	11,327	59.18	9.25	30.13	.12	.10
7. Paper food cartons	2.27	6.11	6.50	7,258	44.74	6.10	41.92	.15	.16
8. Junk mail	3.03	4.56	13.09	6,088	37.87	5.41	42.74	.17	.09
9. Vegetable food wastes	2.52	78.29	1.06	1,795	49.06	6.62	37.55	1.68	.20
10. Citrus rinds, seeds	1.68	78.70	0.74	1,707	47.96	5.63	41.67	1.11	.12
11. Meat scraps cooked	2.52	38.74	3.11	7,623	59.59	9.47	24.65	1.02	.19
12. Fried fats	2.52	0	0	16,466	73.14	11.54	14.82	.43	.07
13. Leather	.42	7.46	21.16	7,243	42.01	5.32	22.83	5.98	1.00
14. Rubber composition heel sole catch	.42	1.15	29.74	10,899	53.22	7.09	7.76	.50	1.34
15. Vacuum cleaner	.84	5.47	30.34	6,386	35.69	4.73	20.08	6.26	1.15
16. Evergreen trimmings	1.68	69.00	.81	2,708	48.51	6.54	40.44	1.71	.19
17. Flower, garden plants	1.68	53.94	2.34	3,697	46.65	6.61	40.18	1.21	.26
18. Lawn grass, green	1.68	75.24	1.62	2,058	46.18	5.96	36.43	4.46	.42
19. Ripe tree leaves	2.52	9.97	3.82	7,984	52.15	6.11	30.34	6.99	.16
20. Tissue paper	2.18	7.00	.93	6,999	43.9	6.1	49.0	....	....
21. Wood	2.52	24.00	2.28	6,840	49.0	6.0	42.0	....	....
22. Plastics (average)	.84	0	0	15,910	78.0	9.0	13.0	....	....
Plastics (high)		0	0	19,303	90.0	10.0	....	....	....
Plastics (low)		0	0	9,580	55.8	7.0	37.2	....	....
23. Rags	.84	7.00	0.93	6,999	43.9	6.1	49.0	....	....
24. Paints, oils	.84	0	0	12,780	52.1	13.1	34.8	....	....
25. Dirt	1.68	0	100.00	0	....	....	....	....	....
26. Metals	7.53	0	100.00	2,660	....	....	....	....	....
27. Glass, ash, ceramics	8.50	0	100.00	0	....	....	....	....	....

APPENDIX D

History of East Coast Incinerator–Boiler Installations

Atlanta, Ga. The Mayson plant at Atlanta, Ga., contains four International Volund rotary kiln furnaces, each followed by a two-drum bent tube boiler located in the furnace flue. The first two units were constructed in the early 1940's, followed by two additional units in the early 1950's. Flue gas temperatures entering the boilers are in the range of 1,500° F. to 1,800° F. The original boiler tube life was about 15 years. Steam generated in this plant is sold to a local steam heating system. The present condition of the boilers is considered satisfactory. Hand cleaning is resorted to for removing accumulated tube deposits during boiler shutdowns about every 2 weeks.

Miami, Fla. The No. 1 plant in Miami, Fla., contains six circular hearth batch feed furnaces divided into two groups of three furnaces each. Each group of three furnaces has a long common flue with a secondary combustion chamber at each end. Each of the four secondary combustion chambers is associated with a two-pass boiler. Each boiler is provided with a gas bypass flue with spray cooling. This plant was placed in operation in 1955. Flue gas temperatures entering the boilers average about 1,500° F. Steam generated in this plant is delivered to an adjacent hospital. The present condition of the boilers is considered satisfactory. Hand cleaning of tubes is performed about four times a year during boiler shutdowns.

Town of Hempstead, N.Y. The Merrick plant in the town of Hempstead, N.Y., contains four circular hearth batch feed furnaces divided into two groups of two furnaces each. Each pair of furnaces discharges flue gas through a common secondary combustion chamber and flue into a boiler. This plant was placed in operation in 1951 and the boilers were retubed after about 8 years of operation. Flue gas temperatures entering the boilers vary from 1,200° F. to 2,000° F. The steam generated is used in the plant for electric power generation with excess steam going to a condenser. It is currently reported that approximately 50 percent of the boiler tubes are being removed to investigate the effect on tube fouling. The boilers are taken off the line on alternate weekends for inspection and manual cleaning.

Providence, R.I. The Field Point plant in Providence, R.I., contains two furnaces, each of which discharges into two boilers. The first two boilers and furnaces were placed in service in 1936 and retubed in 1956. The second two boilers and furnaces were placed in service in 1950. Replacement of the first two rows of boiler tubes has been maintained on a continuous basis. Combustion chamber temperatures range from 1,900° F. to 2,500° F. One boiler and one furnace are normally operated to provide steam for an electric generator, which in turn provides power for the local incinerator and sewage plant. Hand cleaning of the boilers is performed about every 2 weeks during shutdown of one boiler associated with the operating furnace. All of the boilers are currently undergoing repairs with steam generation to continue only on a limited basis.

Oyster Bay, N.Y. The plant at Oyster Bay, N.Y., has two boilers, each fired by a pair of rectangular grate batch feed furnaces. These boilers operated on a controlled bypass system to maintain desired boiler pressure. The steam was used for heating and electric power generation for the plant. The plant was placed in operation about 1956 and the boilers were retubed in 1961 because of internal corrosion. Gas temperature entering the boilers averaged about 1,200° F. Hand cleaning of the gas side of the boiler was required about every 4 months. The boilers have been removed from service.

Boston, Mass. The South Bay plant in Boston, Mass., has three waste heat boilers. Each is installed in a flue fed by two rectangular batch feed furnaces. Boiler bypass flues are provided for each furnace. The plant was designed to supply steam to a nearby hospital and was placed in operation in 1959. Average gas temperature entering the boilers is approximately 1,300° F.

Moderate amounts of steam are generated for local plant use only. The steam supply to the hospital has been discontinued.

Town of Hempstead, N.Y. The Oceanside plant in the town of Hempstead contains two integral refractory furnace–convection boiler units with continuous feed furnaces. This plant was placed in service in 1965. The steam is used to generate electric power for use in the plant. The excess steam is used to distill seawater. Gas temperatures entering this boiler range upwards from 1,725° F. One of the units is presently out of service for the addition of more retractable soot blowers and the replacement of some tubes which have failed, apparently by external damage.

Norfolk Navy Yard. A new incinerator boiler plant containing two waterwall furnaces with integral boilers was to be placed in service at the Norfolk Navy Yard early in 1967. This will be the first water-cooled furnace incinerator boiler plant in the United States. It is designed to operate at excess air levels of 50 percent or less when burning refuse. It is equipped with auxiliary oil firing and will supply port-use steam (standby service for ships at dock) for the Navy Yard.

REFERENCES

(*1*) KAISER, E. R. Chemical analyses of refuse components. Paper 65-WA/PID-9. *In* Proceedings, American Society Mechanical Engineers, Nov. 7-11, 1965. 5 p.

(*2*) EBERHARDT, H. European practice in refuse and sewage sludge disposal by incineration. I. *Combustion*, 38(3): 8-15, Sept. 1966.

(*3*) EBERHARDT, H. European practice in refuse and sewage sludge disposal by incineration. II. *Combustion*, 38(4): 23-29, Oct. 1966.

(*4*) DEMING, L. F. Navy contemplates steam generating incinerator. *Public Works*, 96(7): 92-94, July 1965.

(*5*) STABENOW, G. Survey of European experience with high pressure boiler operation burning wastes and fuel. *In* Proceedings, 1966 National Incinerator Conference, American Society of Mechanical Engineers, New York, May 1-4, 1966. p. 144-160.

(*6*) BENDER, R. J. Incineration plant—plus. *Power*, 111(1): 62-64, Jan. 1967.

can-metal recovery

ABSTRACT

THIS REPORT reviews the possibilities of recovering ferrous metal from municipal refuse either before or after incineration. The study indicates that the only major existing market for this material (after incineration) is the copper industry which can preferably use that iron derived from old tin cans. This market is currently being satisfied.

The capital investment required and the operating costs to be expected for an installation to recover ferrous can metal from the residue of a new 800-tons-per-day incinerator planned for the District of Columbia have been estimated. Because of the low price obtainable for recovered can metal and the high cost of freight to the one sizable market, it is concluded that facilities of this type should not be included in the new District of Columbia incinerator project.

INTRODUCTION

AS THE MAGNITUDE and cost of disposing of solid municipal refuse continues to grow it becomes more incumbent on governmental authorities to find ways of salvaging material of potential value mixed with the refuse. This is important not only as a means of reducing the cost of these services but also to conserve natural resources. One major component of refuse is steel, especially that from discarded metal cans.

Very little scrap metal is being salvaged by municipalities. This material is being dissipated in landfills either as collected with other refuse or as incinerator residue. Thus this potential source of iron is being rendered unavailable for future recovery.

The purpose of this report is to study the methods whereby waste metal may be recovered from refuse and the economics of the most feasible method, specifically in relation to Incinerator No. 5 as proposed for the District of Columbia.

This report does not include the recovery of metal from shredded bulky objects such as refrigerators because this type of scrap metal is not adaptable to the shredded can-metal market.

SUMMARY AND RECOMMENDATIONS

At the present time no satisfactory method exists for economically extracting scrap can metal from ordinary municipal refuse prior to incineration. Those communities that do not have incinerators therefore discard this can metal in sanitary landfills with their other refuse.

Ferrous metal can be recovered from incineration operations provided a complete burnout of the residue is achieved. The equipment required is relatively simple but the manpower needed is somewhat costly. The market for this material is extremely limited and freight to the point of use generally must be paid by the shipper.

The largest existing market is for shredded can metal which is used in copper mining. Since this industry can readily get as much of this material as it needs, a buyer's market exists.

The estimated investment cost for a can-metal recovery system for the proposed 800-ton-per-day Incinerator No. 5 in the District of Columbia is $400,000. Operating costs including amortization are estimated to be $13.60 per ton of metal reclaimed. Freight charges to southwestern United States would add approximately $83 per ton to this cost. The critical limiting price including frieght is reported to be $75 per ton. No guarantee can be made that the sale price for this metal will increase.

The lack of profit does not justify the capital expenditure required for installation of metal recovery equipment at this time. It is, however, recommended that consideration be given in the design of the proposed incinerator plant to the possible future addition of ferrous metal recovery equipment.

Periodic contacts should be maintained with the metal market so that if additional markets for recovered metal are developed, the necessary equipment may be installed in this plant.

SOURCE AND QUANTITY OF METAL WASTE

Most municipalities gather tin cans along with discarded bottles, plastic containers, paper, wood,

Preceding page blank

miscellaneous other metal and sometimes garbage, in a single collection. Data on the percentage of tin cans and miscellaneous metal contained is exceedingly sparse. One source (*1*) reports a range of values from 3.1 to 11.6 percent by weight for total metal with an average of about 8 percent. A spot analysis of incinerator residue from four installations in or near Washington, D.C. (2), indicates that can metal accounted for 63 percent of the ferrous metal present and that nonferrous metal was less than 1 percent. This would indicate that nonferrous metal can be neglected as far as this study is concerned. Applying the 63 percent can metal in the residue to the 8 percent overall metal in the rubbish as collected results in a figure of 5 percent for the overall content of can metal.

Production of refuse in the United States is currently estimated at 1,600 pounds per year per person (*1*). All of this is not necessarily suitable incinerator charge, however, since it includes residential, commercial, demolition, and industrial refuse. A more realistic figure for total combustible materials would be in the order of 800 to 1,000 pounds per year per person. Thus the potential annual tonnage of scrap tin plate in refuse may be estimated as follows:

$$\frac{1000 \text{ lbs./capita/yr.} \times 200{,}000{,}000 \text{ persons} \times 5\%}{2000 \text{ lbs./ton}} = 5{,}000{,}000$$

In 1966 tin plate was being consumed by can manufacturers at a rate of 4,900,000 tons per year (3). It might also be noted that in 1965 a total of 7,331,057 tons of steel was consumed in the form of containers, packaging, and shipping materials (*4*). These tonnage figures indicate that the percentage figures for metal in refuse are reasonably accurate.

By the above reasoning it might be concluded that recoverable metal cans in municipal refuse as collected would be about 5 percent by weight. However, experience at specific plants indicates considerable variation from this figure. These variations are due to difference in geographical location, the season of the year, the economic position of the people served and the specific way in which incinerable refuse is collected. Data for the first 7½ months of 1966 from a specific plant in Atlanta, Ga., where can metal is being recovered (*5*) show an actual yield of 3.78 percent. Therefore, for a planned installation a figure of 3.5 percent by weight for design purposes would be reasonably conservative.

Disposal of Recovered Metal

Ordinary metallic materials encountered in municipal refuse collection operations do not cause special disposal problems if they are not separated from the other material. They can be deposited in sanitary landfills either before or after incineration. But this type of disposal dissipates a material that has a potential value.

Considerable quantities of this metal have been salvaged through the simple expedient of allowing scrap pickers to gather the material at dumps or through segregated rubbish collections. The practice of hand picking metals is rapidly being eliminated because such activities interfere with satisfactory landfill operation. Separation of metals from other refuse before collection is also declining because it has become politically and economically inexpedient to require residents to segregate their refuse. But the overriding cause of abandonment of scrap metal recovery has been the high cost of labor and the low price for which scrap metal can be sold.

Illustrative of the difficulties encountered by municipalities salvaging can metal is the experience of Atlanta, Ga., which has been in this business since 1939. In 1956, shredded metal was bringing $27(*5*) per ton FOB Atlanta. By 1966 this price had declined to $15(*5*).

The American economy is passing through a phase in which changes in manufacturing technology have resulted in low industrial demand for scrap metal and increased quality requirements for scrap metal which industry can use. This situation, however, can and probably will change in the future. It is therefore important that this possibility not be overlooked in planning refuse disposal facilities.

Today's steel industry rejects most scrap from municipal collections because it contains too many contaminants. The principal objections are the tin plating and the contents of unshredded cans. Detinning plants are currently being operated but they will only accept clean scrap which is produced in can manufacturing plants. The economics of recovering tin from used cans are unfavorable.

Can-metal temperatures in the range of 1,400° to 1,500° F. during incineration will cause the tin coating to be removed but at higher temperatures there is the possibility of oxidation of the thin parent metal which will degrade the value of the product. When can metal is processed at acceptable temperatures and shredded, it is acceptable to the copper industry (*see* below) but elsewhere it cannot compete with the abundance of iron and steel melting scrap resulting from the demolition of automobiles and other bulky objects.

It is important to note that nearly all scrap metal users prefer shredded metal to metal compressed into bales. The principal reason for this is that the final scrap product can be passed through a magnetic separator which will reject contaminants not hitherto eliminated. For this reason the trend in commercial scrap yard operation is toward the use of shredders in place of baling presses.

A big disadvantage of shredded material as compared to baled metal is the low bulk density. This is especially true in the case of can metal. Shredded cans have a bulk density of 20 to 25 pounds per cubic foot compared to 150 pounds per cubic foot for baled metal. This is an important factor in the high cost of shipping shredded can metal.

Some markets of limited demand for shredded can metal are understood to exist in the eastern United States for end uses such as the manufacture of ferroalloys, but information on these markets is very meager.

The only significant market at present for this type of scrap is the copper mining industry which is centered principally in our western States and Mexico. This market cannot absorb all the scrap metal that can be salvaged, therefore the buyer can be very particular about the quality of the material accepted. The scrap steel is used in a copper leaching process in which the ratio of exposed metal surface to the bulk involved should be as high as possible. Shredded metal cans are admirably suited for this use compared to other forms of steel scrap. Thus, it is desirable to remove any heavy iron that may be recovered and also to shred the cans before shipping the product to be used for this purpose.

Competition for the available market also makes it necessary for the seller to absorb the freight charges. The shredded metal is heaped in open gondola cars but, as stated previously, the bulk density results in abnormally high freight rates. A figure of $4.15 per cwt. from Washington, D.C., to either Arizona or Utah has been quoted by a major eastern railroad (*6*).

Prices paid during 1966 at copper mines in the southwestern United States ranged from $52 to $62 per ton of reclaimed can metal delivered. The critical limiting price is estimated to be about $75 per ton for top quality material (*7*). It is evident that the freight charges from Washington, D.C., to the delivery point would exceed the current selling price for this reclaimed scrap.

Because the copper companies need large and particularly stable sources of supply, they frequently contract with scrap metal firms specializing in this type of metal. A list of copper and scrap metal firms who are in the market for incinerated can metal is included as appendix F. It is apparent that firms in the scrap metal salvage industry possess considerable proprietary information as to the nature and magnitude of the scrap metal market which is not available to the general public. A national association of the scrap iron and steel processing industry has offered the benefit of their considerable knowledge in the field of scrap (*8*).

AVAILBALE METAL RECOVERY METHODS

Before Incineration

The only proven method of segregating metal from solid waste as collected is by the use of manual pickers. The economics of this operation obviously are dependent on the cost of labor and the market for the recovered metal.

Attempts have been made to use a magnetic separator for this purpose but the lack of homogeneity and low metal concentration in the charge material has resulted in an extremely inefficient operation.

On the west coast the value of scrap metal is higher and smog conditions are severe. The smog conditions have restricted the use of incineration and as a result, attempts have been made to remove metal with a mechanical picker or sorter. However, there is no known successful installation. Further consideration of metal salvage before incineration will require development of a suitable method of mechanical separation of refuse and metal.

After Incineration

The recovery of ferrous metal from incinerator residue is feasible and profitable under certain conditions. It is being practiced at a number of incineration plants in different parts of the country (see app. F).

Of the 11 plants currently in operation, it should be noted that seven are of the rotary kiln type and that three new plants under construction are also of this type. This is attributable to the high quality of burnout of residue that can be achieved in this type of design. However, this does not rule out other continuously fed incinerators of modern design which can achieve an equally good burnout.

An acceptable procedure for recovering the metal is to first pass the furnace ash residue from the incinerator over screens where the nonmetallic ash type of material is washed from the cans and discharged through the screen surface into residue trucks for hauling to a landfill. Rotary screens are preferred over the vibrating type. The latter work best when the solid material being retained is roughly spherical in shape and bounces easily. The rotary screen is not hampered as much by jagged points of metal catching in the screens.

The washed can material in a typical installation is discharged from the ends of the rotary screens into a drag conveyor which elevates the cans and discharges them into a storage bin. This storage bin is installed in the plant to permit the operation of the metal shredding and separation system on an 8-hour-per-day, one-shift basis. Normally there is not enough can metal to justify the labor costs of a three-shift operation of the entire system.

A constant inspection must be made of all residue entering the rotary screens to remove material such as wire, heavy metal, and masonry, which might foul the screens, interfere with subsequent operations or degrade the product. Also, residue containing large amounts of unburned refuse as a result of improper incinerator operation can cause difficulty at the wash screens.

Material is removed from the can storage bin during the day and fed continuously to a can shredder. This machine employs rotating hammers to tear the cans by impact and discharges the pieces through a grate which will pass metal objects of the size acceptable to the purchaser. The processed material then passes through a magnetic separator where the nonmagnetic material is discharged for removal from the system. The magnetic material is transported to a car or truckloading hopper (figure 17).

Capital Investment and Operating Costs

It is estimated that the additional equipment required to process the residue from the proposed Incinerator No. 5 in order to recover can metal could be purchased and erected for $400,000 as tabulated below:

Site preparation and complete structures	$111, 000
Equipment, installed including electrical	192, 000
Railroad siding	25, 000
Engineering including field inspection and supervision	24, 000
Contingency and escalation	48, 000
	400, 000

These costs are based on the layout shown in figure 17. It is perfectly feasible to erect most of this equipment on open steel framing outside of the incinerator building. The estimate is based on this type of installation without an enclosure or architectural treatment.

Estimated annual operating expenses would total $99,350 as shown below.

Inspection at rotary screens (1 laborer, 3 shifts)	$18, 000
Day-shift operator labor (2 operators, part-time foreman)	18, 850
Maintenance	8, 400
Electric power	3, 500
Subtotal	48, 750
Annual fixed charges (10-year life at 4½ percent interest)	50, 600
Total annual operating expense	99, 350

Using the figure of 3.5 percent by weight mentioned earlier in this report as the quantity of can metal that can be recovered based on incinerator charge, the new 800-ton-per-day incinerator plant would produce 28 tons of shredded can metal per day. When operating 5 days per week and 52 weeks per year, the annual production would be 7,300 tons. Therefore the cost of recovering can metal would be $13.60 per ton including amortization charges.

APPENDIX E [1]

INCINERATORS PRACTICING METAL SALVAGE

Location	Plant	Year built	Type furnace
Atlanta, Ga	Mayson	1939	Rotary kiln.
Quebec, Province of Quebec.		1955	Batch circular.
Louisville, Ky		1957	Rotary kiln.
Chicago, Ill	Southwest	1963	Do.
Atlanta, Ga	Hartsfield	1963	Do.
Broward County, Fla.[2]	No. 1	1964	Contin. recip.
Do.[2]	No. 2	1964	Do.
Chicago, Ill	Stickney (Private).	1958	Rotary kiln.
Do	Bolda (Private)		Do.
Do	Medill	1956	Batch, rock. grate.
Do	Calumet	1959	Rotary kiln.
Tampa, Fla		[3] 1967	Do.
Dayton, Ohio	Montgomery County.	[3] 1967	Do.
De Kalb County, Ga		[3] 1967	Do.

---

[1] Data from Bureau of Mines, College Park, Md.

[2] Currently metal recovery not in operation due to lack of market for product. No provision at these plants for washing or shredding of cans from residue.

[3] Not completed. Planned metal salvage facilities.

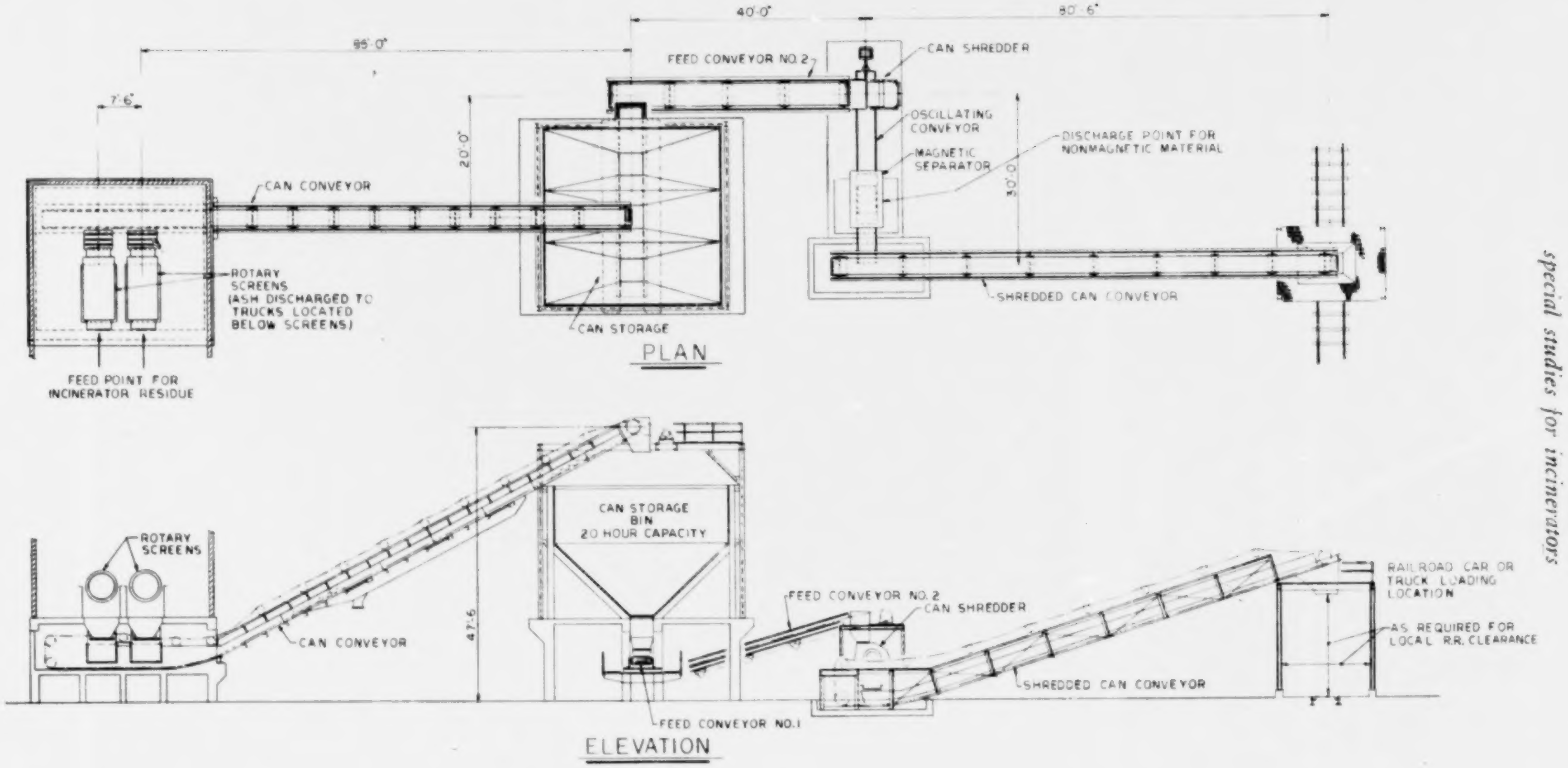

40'0"
80'6"
85'0"
7'6"
20'0"
30'0"
FEED CONVEYOR NO.2
CAN SHREDDER
OSCILLATING CONVEYOR
MAGNETIC SEPARATOR
DISCHARGE POINT FOR NONMAGNETIC MATERIAL
CAN CONVEYOR
ROTARY SCREENS (ASH DISCHARGED TO TRUCKS LOCATED BELOW SCREENS)
FEED POINT FOR INCINERATOR RESIDUE
CAN STORAGE
SHREDDED CAN CONVEYOR
PLAN
ROTARY SCREENS
CAN CONVEYOR
47'6
CAN STORAGE BIN 20 HOUR CAPACITY
FEED CONVEYOR NO.2
CAN SHREDDER
FEED CONVEYOR NO.1
SHREDDED CAN CONVEYOR
RAILROAD CAR OR TRUCK LOADING LOCATION
AS REQUIRED FOR LOCAL R.R. CLEARANCE
ELEVATION

FIG. 17. *General arrangement of can-metal recovery system.*

APPENDIX F

PRIVATE FIRMS IN THE SCRAP METAL INDUSTRY

Proler Steel Corp., 5200 Clinton Drive, Houston, Tex.
Edward Levy Metals, Inc., New Orleans, La.
Los Angeles By-Products Co., 1810 East 25th Street, Los Angeles, Calif. 90058.
Southern Federal Alloys, Chattanooga, Tenn.

REFERENCES

(*1*) AMERICAN PUBLIC WORKS ASSOCIATION. *Municipal refuse disposal.* Chicago, Public Administration Service, 1966. 528 p.

(2) Private communication.

(3) U.S. DEPARTMENT OF COMMERCE. Current industrial reports—metal cans, June 1966.

(*4*) AMERICAN IRON AND STEEL INSTITUTE. Table 24, Shipments of steel products by market classification. *In* Annual statistical report, 1965.

(*5*) Private communication, Atlanta, Ga.

(*6*) Private communication, Pennsylvania Railroad.

(7) Private communication, U.S. Bureau of Mines.

(*8*) Private communication, Institute of Scrap Iron and Steel, Inc., 1729 H Street NW., Washington, D.C. 20006.

U.S. GOVERNMENT PRINTING OFFICE : 1968—O-289-620